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DYNAMIC AND STATIC EVALUATION OF EXPERIMENTAL INTEGRAL FUEL TANK SEALANT MATERIALS

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DYNAMIC AND STATIC EVALUATION OF EXPERIMENTAL INTEGRAL FUEL TANK SEALANT MATERIALS

DOW CORNING CORPORATION
Midland, Michigan 48640

DECEMBER 1974

Final Report for Period 1 May 1972 - 31 July 1974

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This final technical report describes the investigation and evaluation of experimental integral fuel tank sealants under laboratory conditions simulating aircraft integral fuel tanks.

Materials investigated were Dow Corning® 77-028, 77-085, 3M Polyester, TRW Polyimide, Polysulfide and AFML Viton. These materials were evaluated dynamically in a fillet sealed con-

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figuration. This report also describes in detail the functions, operations and problems encountered with the dynamic test apparatus that has been designed and fabricated for the purpose of evaluating experimental aircraft integral fuel tank sealants. A portion of the effort was required to diagnose deficiencies and mechanical failures of the testing equipment which resulted in the lack of conclusive data in the report. As a result of these problems, no conclusions can be made on the materials tested.

Personnel with expertise in the design and fabrication of testing devices were solicited to critique the present sealant testing apparatus and requested to submit recommendations for modification or redesign. The proposed modifications and design plans furnished by these firms are described and the recommended design is explained.

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This final report was prepared by Encapsulants and Sealants Technical Service and Development Laboratory, Dow Corning Corporation, Midland, Michigan, under Contract Number F33615-72-C-1594, Job Order Number 73400540, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. W. F. Anspach (MBE) was the Project Engineer.

This technical report has been reviewed and is approved for publication.

William F. Anspach

W. F. ANSPACH
Project Engineer

FOR THE COMMANDER

Merrill L. Minges

MERRILL L. MINGES, Chief
Elastomers and Coatings Branch
Nonmetallic Materials Division
Air Force Materials Laboratory

PREFACE

This final report was prepared by Encapsulants and Sealants Technical Service and Development Laboratory, Dow Corning Corporation, Midland, Michigan, under Contract Number F33615-72-C-1594. The contract work was performed under Project 7340, "Nonmetallic and Composite Materials," Task No. 734005, "Elastomeric and Compliant Materials," and was administrated under the direction of the Elastomers and Coatings Branch, Nonmetallic Materials Division, Air Force Materials Laboratory, Wri^ht-Patterson Air Force Base, Ohio, with W. F. Anspach as Pr' ct Engineer.

The personnel of Dow Cc ing Corporation assigned to this contract during the per.od 1 May 1972 to 1 August 1973 were the following:

Principal Investigator - Mr. G. H. Snyder

Technician - Mr. C. A. Schultz

During the period from August 1973 to 31 July 1974, personnel assigned to this contract were:

Principal Investigator - Mr. J. H. Baker

Supervisor - Mr. J. E. Matherly

This report was submitted by the contractor December, 1974.

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INTRODUCTION

Objective

The objective of this work was to develop, investigate, and evaluate experimental integral fuel tank sealants for advanced high performance aircraft. These objectives were to be attained under both static and dynamic conditions which simulate the environment and conditions encountered in aircraft integral fuel tanks.

Background

The temperature extremes encountered in the fuel tanks of present and planned supersonic aircraft have pushed currently available fuel containment sealants to the limits of their capability. Now, more than ever before, it is necessary to prove the capability of a fuel tank sealant and predict its service life prior to selection for a particular aircraft.

Although there are "rules of thumb" regarding sealant physical property limits for a particular application, it is not likely that these rules can be confidently applied for all aircraft or sealants under consideration. The greatest problem in doing so is the difficulty in correlating physical properties of statically aged sealant specimens with dynamically stressed sealant in an actual fillet seal configuration.

Although efforts have been made to circumvent the problem by dynamically testing small sealed fuel tank sections, in many cases, these tests require a great deal of assembly time prior to each test, and are frequently quite cumbersome. The amount of material needed to seal one of these tanks makes it very difficult to evaluate experimental sealants which are usually available only in limited quantities.

SECTION II

DYNAMIC TEST DEVICE

A dynamic test device has been designed and fabricated by Dow Corning which takes into consideration size, quantity of sealant required, and simulated environment, so that the apparatus might be a convenient evaluation tool which would be a help to subsequent sealant development programs.

The design of the equipment required the collecting of information on aircraft fuel tank conditions from reliable sources throughout the aircraft industry. The information collected has been covered in a previous report (AFML-TR-72-122), and, as indicated, was in some instances very specific; in other cases based on personal opinion confirmed at several sources; and in other cases rather inconclusive and calling for some degree of judgment in weighing the importance of the information in relationship to the equipment design.

The test apparatus was designed around the idea that sealability is the key parameter in aircraft sealant performance and that sealability depends upon a complex interaction of physical properties and cannot be determined solely from physical property data. Therefore, it was decided that the test would include a representative sealed test joint which would perform

a fuel containment function exactly as it would in an aircraft and failure would be defined as the point at which leakage occurred. To accomplish that end, it was necessary to design and fabricate a test apparatus completely new to the field of materials evaluations. In so doing, the already numerous considerations of the materials evaluation area have been superimposed on the design and procedure problems associated with any new test apparatus of such complexity. Thus, it was necessary to closely scrutinize the validity of each new piece of test data with an eye toward possible improvements in the test procedures and equipment, even if those modifications would reduce the significance of data already accumulated.

Joint Design

In general, the aircraft industry felt the test joint shown in Figure 1 was representative of the average fillet seal. It consists of a circular 3" diameter titanium cup sealed to a titanium plate by the test sealant. Joint deflection is applied by holding the plate stationary at its perimeter and rotating the cup slightly. In addition, areas such as corner joints and fasteners seem to be critical sealing points. The corners because of the multidirectional stresses, and the fasteners primarily because of the large number to be sealed without a flaw.

Joint Movement

The original appar[illegible] included a high frequency vibration input, which, [illegible] by all persons contacted,

TEST JOINT

FIGURE [illegible] - TEST JOINT AND INSTALLATION

was unnecessary. It was, however, suggested that in addition to the torsional deflection originally proposed, there should be a joint opening deflection. The design was subsequently changed to include these modifications. The degree of joint movement depends to some degree on the type and thickness of structural members used. Aluminum military aircraft structures, for example, tend to have rather thick structural members ($^1/_2$" to $^3/_4$" in some locations) and are relatively inflexible. Titanium aircraft, however, due to the type of construction used and the unique nature of the metal, tend to be more dynamic in character.

Those sources contacted regarding aluminum aircraft felt minimal movement should be expected in the sealed joints with which they had experience while one source working with titanium structures felt it was reasonable to expect .008" - .010" maximum movement. In another instance, while specific joint deflections were not available, joint movement in a titanium aircraft has been translated into a sealant requirement of 18 to 20% elongation for satisfactory performance at operating temperatures.

One report (AFTR-6187) was cited as measuring the actual deflections on a B-45 aircraft by mounting a deflection meter on a structural member and monitoring the movement of the aircraft skin during flight. The report indicated frequent deflections of .005" and occasional deflections up to .030". Although this was not a current work, it was concluded by the source that it should be relatively applicable to present aircraft.

SECTION III

PRINCIPLES AND MECHANICS OF EQUIPMENT OPERATION

Figure 2 shows a cross-section of one of the three test cylinders. Each cylinder is divided into a primary and secondary chamber by a titanium diaphragm. A circular 3" titanium cup sealed onto the diaphragm with the test sealant acts as the test joint, and effectively separates the two chambers by covering four $^5/_8$" openings in the diaphragm. Heat is applied to the cylinders via radiant heat lamps capable of producing +600°F, and the cylinders can be cooled to a possible -65°F by LN_2 injection through cooling coils welded to the interior of the chambers. Jet fuel and fuel vapor can be cycled in the primary chamber at temperatures prescribed by the fuel tank temperature of the aircraft for which the sealants are being tested.

A hollow shaft through the lower chamber, attached to the test cup by means of a splined socket arrangement, is used to effect a torsional displacement of the cup. A solid shaft running through the hollow tube contacts the back side of the titanium diaphragm, and, through the use of a pneumatic cylinder, deflects the diaphragm, thereby causing an opening of the sealed joint around the perimeter of the test cup. The degree of displacement as well as the number of displacements per unit time can be adjusted to approximate the conditions in a particular aircraft.

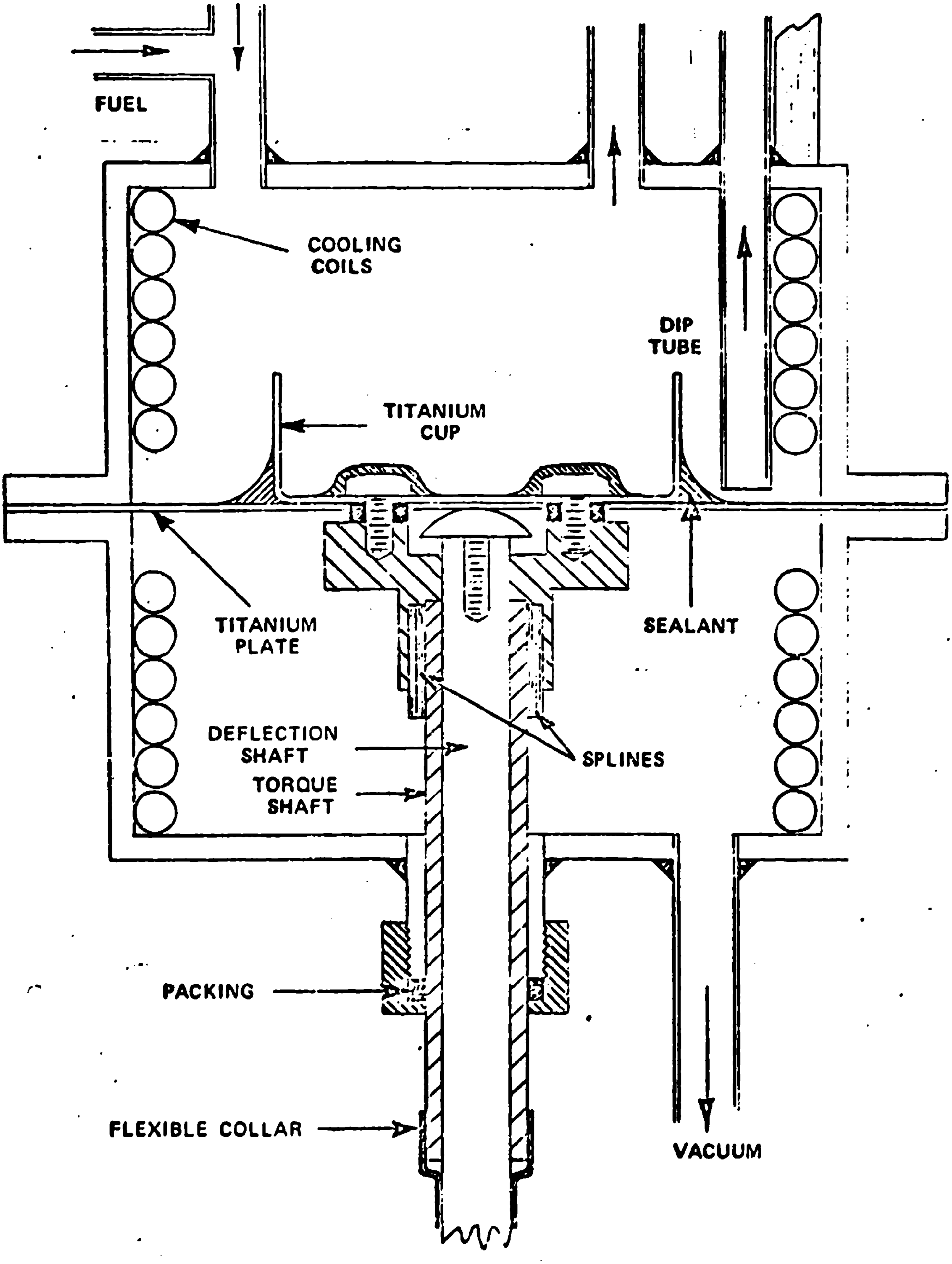


FIGURE 2 - DYNAMIC TEST CHAMBER

Pressures in the two chambers are regulated in such a manner that the secondary chamber is at a slightly lower pressure than the primary chamber. In the event of a sealant failure during the course of a test, fuel or fuel vapor enters the secondary chamber and is sensed by a detection apparatus. A relay activated by the detection circuit shuts off the fuel supply, heat and refrigeration. Failure is visually indicated by a pilot lamp.

Temperature Profile

Most military aircraft encounter peak skin temperatures of 375°F or less, with the peak temperature usually accounting for less than 5% of the total flight time. The remaining flight time consists of moderate speeds generating skin temperature between 200°F and 300°F, or subsonic speeds possibly accompanied by sub-zero skin temperatures.

Of more concern, at present, are aircraft cruising at extremely high speeds. Maximum skin temperatures for the SST were projected at 440° - 450°F at certain points on the aircraft. Approximately 70 - 75% of the flight time was to have consisted of peak temperature exposure, requiring a fuel containment sealant, ideally, to last approximately 30,000 hours at that temperature.

Even more stringent are the temperature requirements of the SR-71 type of aircraft which generate peak temperatures in the

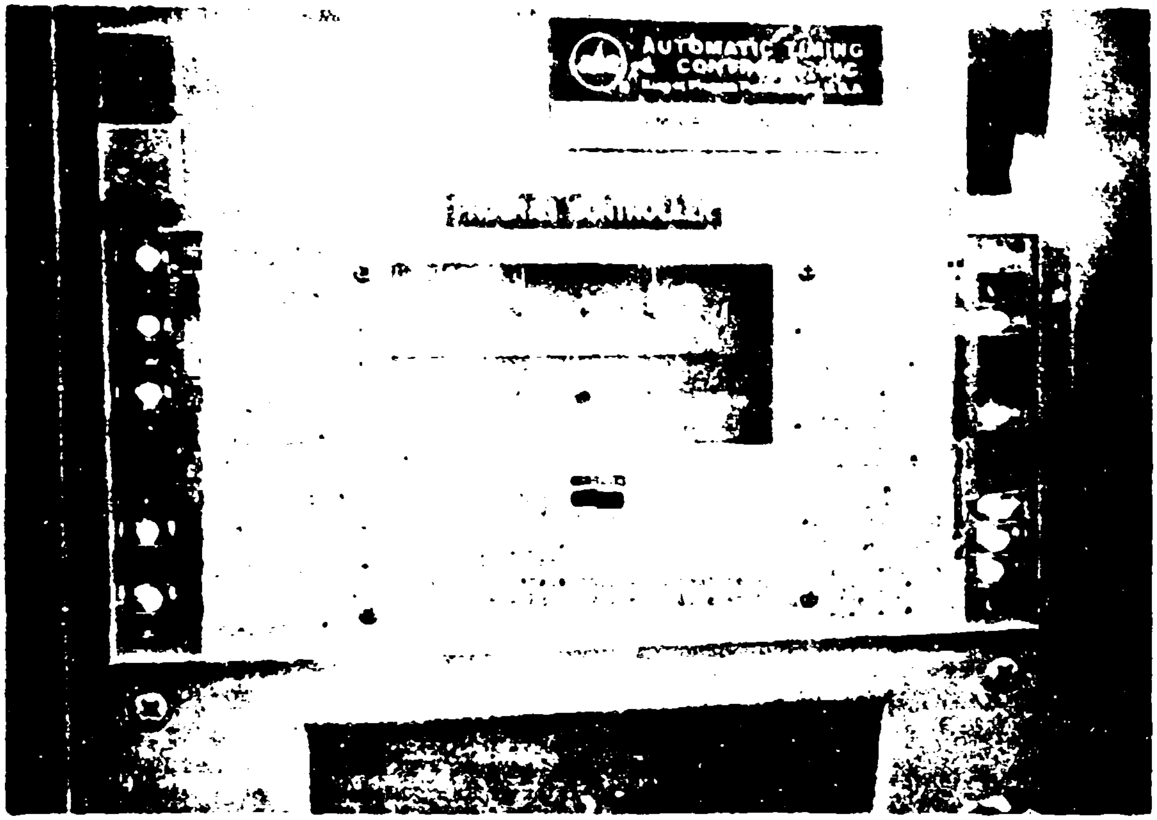
550° - 600°F range, with the peak temperature again accounting for a large percentage of the total flight time.

Sub-zero temperature extremes have been the subject for much discussion. The generally accepted low temperature extreme is -65°F, but at least two sources felt that -65°F was unrealistically low. Only one instance of actual temperature measurement was cited, with the lowest temperature being recorded at -45°F during flight at subsonic speeds. It is conceivable, however, that ground temperatures down to -65°F could be encountered by an aircraft in isolated instances, and that a sealant with poor low temperature flexibility might be caused to fail due to the high joint deflections present during taxi and takeoff.

Test Cycle Programming

Testing consists of repetition of a simulated aircraft flight cycle. In order to synchronize the various test functions such as heat, refrigeration, etc., a program card timer capable of switching up to 30 functions is used for all three units. This instrument uses programmable plastic cards and provides a wide latitude of possible simulated test conditions (Figure 3).

The following test cycle has been used on all specimens to date: (Note: temperatures are merely representative.)



PROGRAM TIMER

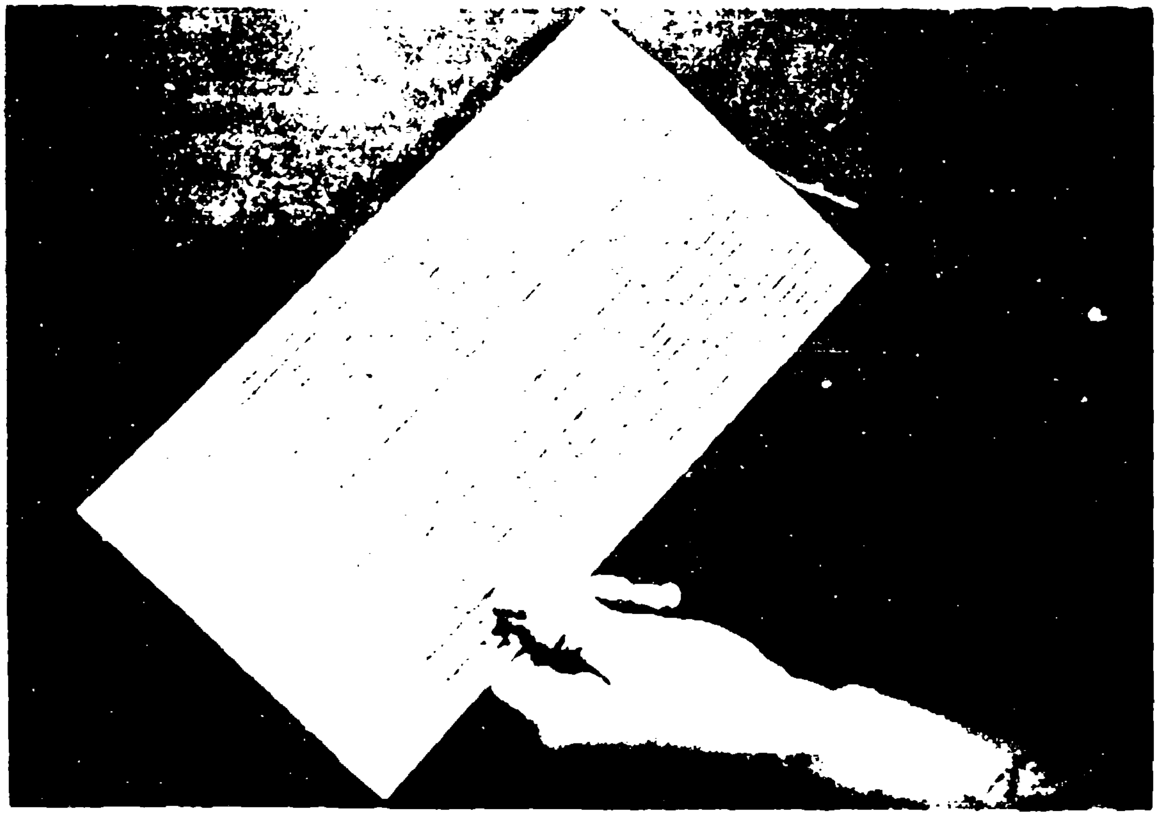


FIGURE 3 - PROGRAM TIMER AND PROGRAM CARD

Cumulative Time	Test Conditions
0 hours	Pressure control on, fuel bypass line open to fill chamber, fuel metering valve set at 2 cc/min; all other functions off.
0.30 hours	Fuel bypass closed, joint deflection on. Heat on; temperature rises to 250°F.
1.00 hours	Fuel evacuated from chamber; temperature rises to 550°F.
2.50 hours	Heat off; deflection off.
2.77 hours	Recycle to time 0.

Test Equipment Capabilities

Based on specifications set forth at the inception of this contract, as well as the information summarized in the preceding sections, the dynamic test device (refer to Figures 2 through 6) was designed to include the following capabilities:

1. Temperature capability between -65°F and 600°F with either extreme obtainable within 15 minutes.
2. Torsional deflection - adjustable over at least 0-.030" rotary movement measured at the perimeter of the test cup. Rate of deflection covers a range of 0-30 deflections per minute, both clockwise and counter-clockwise.
3. Joint opening deflection - adjustable over at least 0-.030" opening at the perimeter of the test cup. Deflection rate is adjustable between 0-100 deflections per minute.

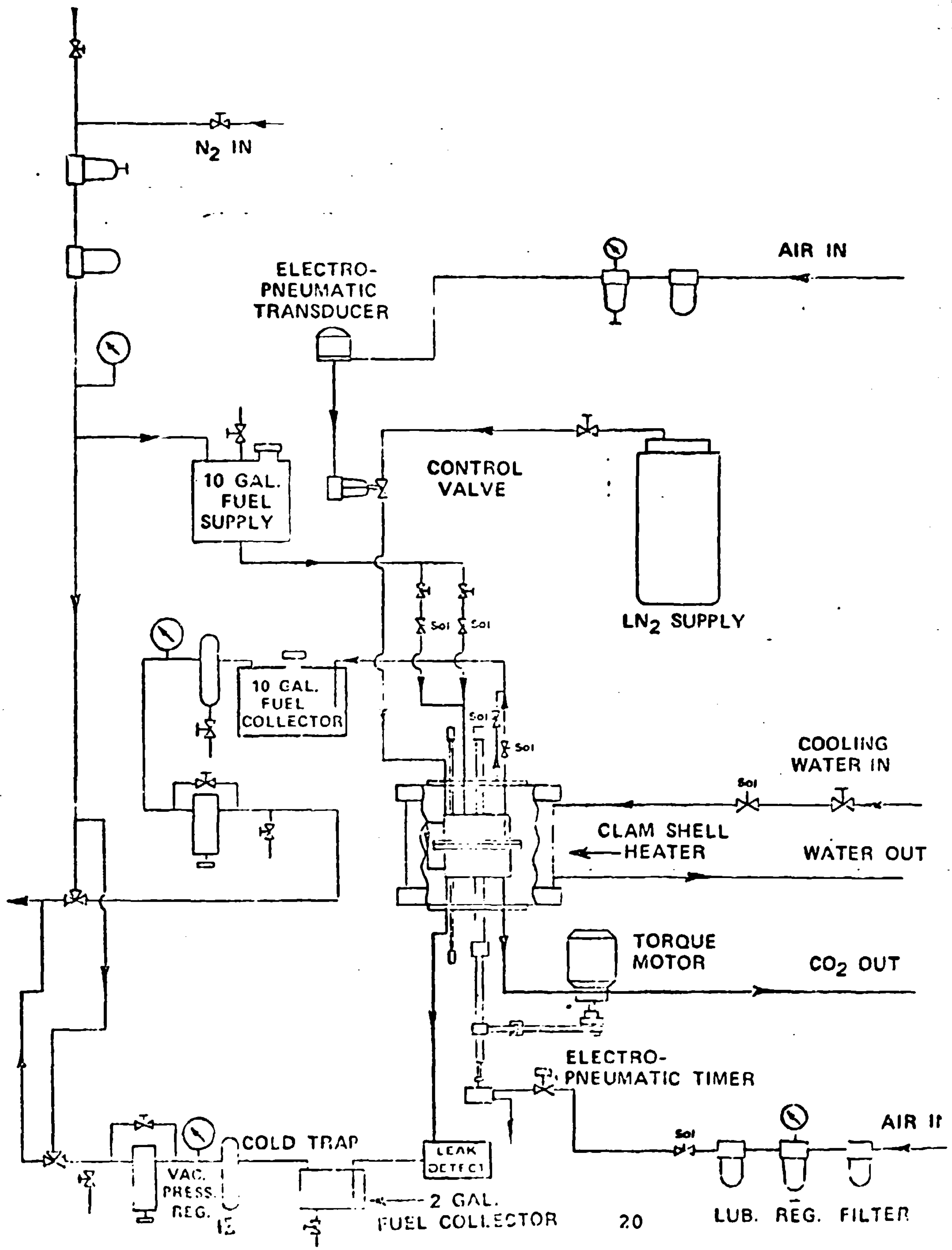
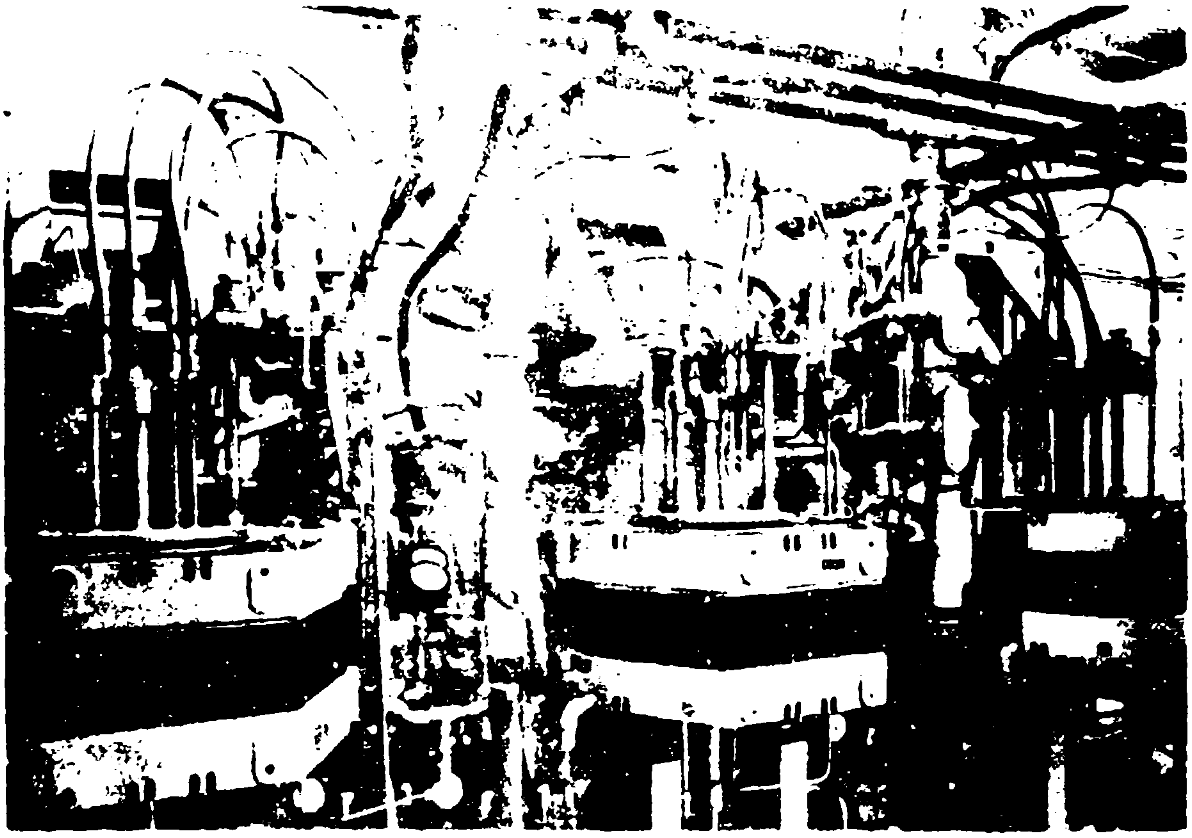


FIGURE 4 - PIPING/MECHANICAL SCHEMATIC



TEST CHAMBERS AND ASSOCIATED HARDWARE

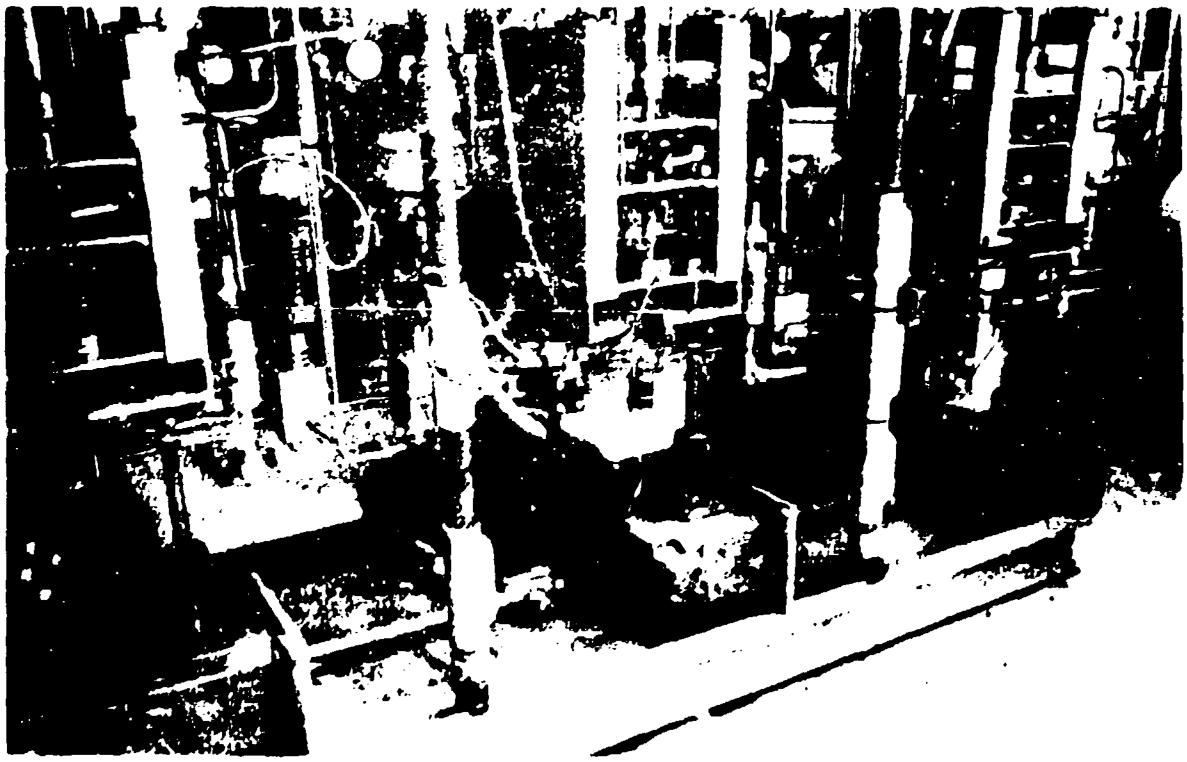


FIGURE 5 - TEST CHAMBERS (ABOVE) AND DEFLECTION ASSEMBLY

MASTER CONTROL PANEL

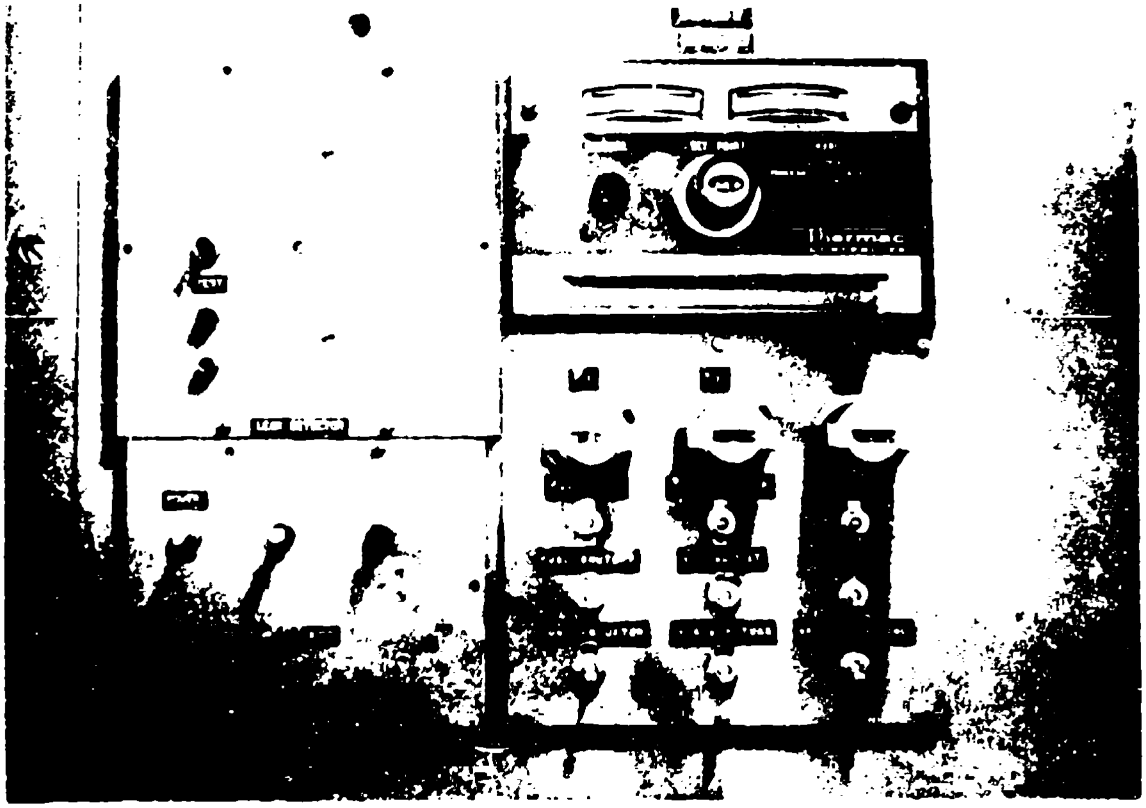


FIGURE 6 - MASTER CONTROL PANEL (ABOVE) AND INDIVIDUAL UNIT CONTROLS

4. Chambers may be evacuated, pressurized with air or nitrogen, or the air or nitrogen may be bled into the chambers while evacuated.
5. Fuel may be metered into the chambers at an adjustable rate, or they may be filled at a more rapid rate through a separate fuel line. Fuel may also be rapidly evacuated from the chambers at any time.
6. Sealant failure, indicated by leakage of fuel through a test joint, is detected by a liquid sensing thermistor circuit in the vacuum outlet of the secondary chamber. When leakage is detected, the sensor automatically terminates operation of the affected chamber.
7. All test functions are controlled by a program card timer which can be programmed for the desired sequence of events and recycled indefinitely.

SECTION IV

SEALANT MATERIALS

Sealants evaluated under this program included:

1. Polysulfide (MIL-S-8802)
2. Polyimide (TRW)
3. Polyester (3M-EC-2288)
4. Low Modulus Fluorosilicone (Dow Corning 77-085)

Evaluation of these materials, which were exploratory in nature, will hopefully provide a base from which to direct further studies.

Physical Property Determinations

The sealant specimens used in the static aging were prepared and tested as follows: Die "C" tensile specimens and Die "B" (ASTM-D412) tear specimens were cut from the cured slabs. These were then tagged, weighed and placed in the fuel vapor aging chamber. As specimens were removed from the chamber after aging, they were heated in a circulating hot air oven for 2 hours at 200°F to remove any absorbed jet fuel, then reweighed to determine weight loss.

Tensile strength, tear strength and elongation were then determined on an Instron test apparatus at room temperature, the

temperature at which the aging was performed and, in some cases, at a selected sub-zero temperature such as -45°F.

Static Fuel Vapor Aging

Fuel vapor aging was performed using the apparatus shown in Figure 7. Tensile and tear specimens were pre-weighed and placed into the test chamber in stainless steel mesh baskets. The chamber was sealed and vacuum was applied to maintain an internal pressure of 4 psia. JP-7 jet fuel was metered into the chamber at approximately 2 cc/min. and the temperature was raised to a point coinciding with the high temperature vapor portion of the dynamic test cycle. The jet fuel supply system used only new fuel, which was discarded after each test.

Several specimens were removed from the chamber at selected intervals of aging, and physical properties were determined after the specimens were dried for 2 hours at 200°F and reweighed for weight loss determination. Total aging time coincided approximately with the total high temperature dwell time experienced by the material in the dynamic test up to the failure point of the fillet sealed test specimen.

Static Test Results

The critical area for concern is the relatively poor properties at 550°F. Hot elongation and tear propagation resistance are particularly important when viewed in relationship to the dynamic

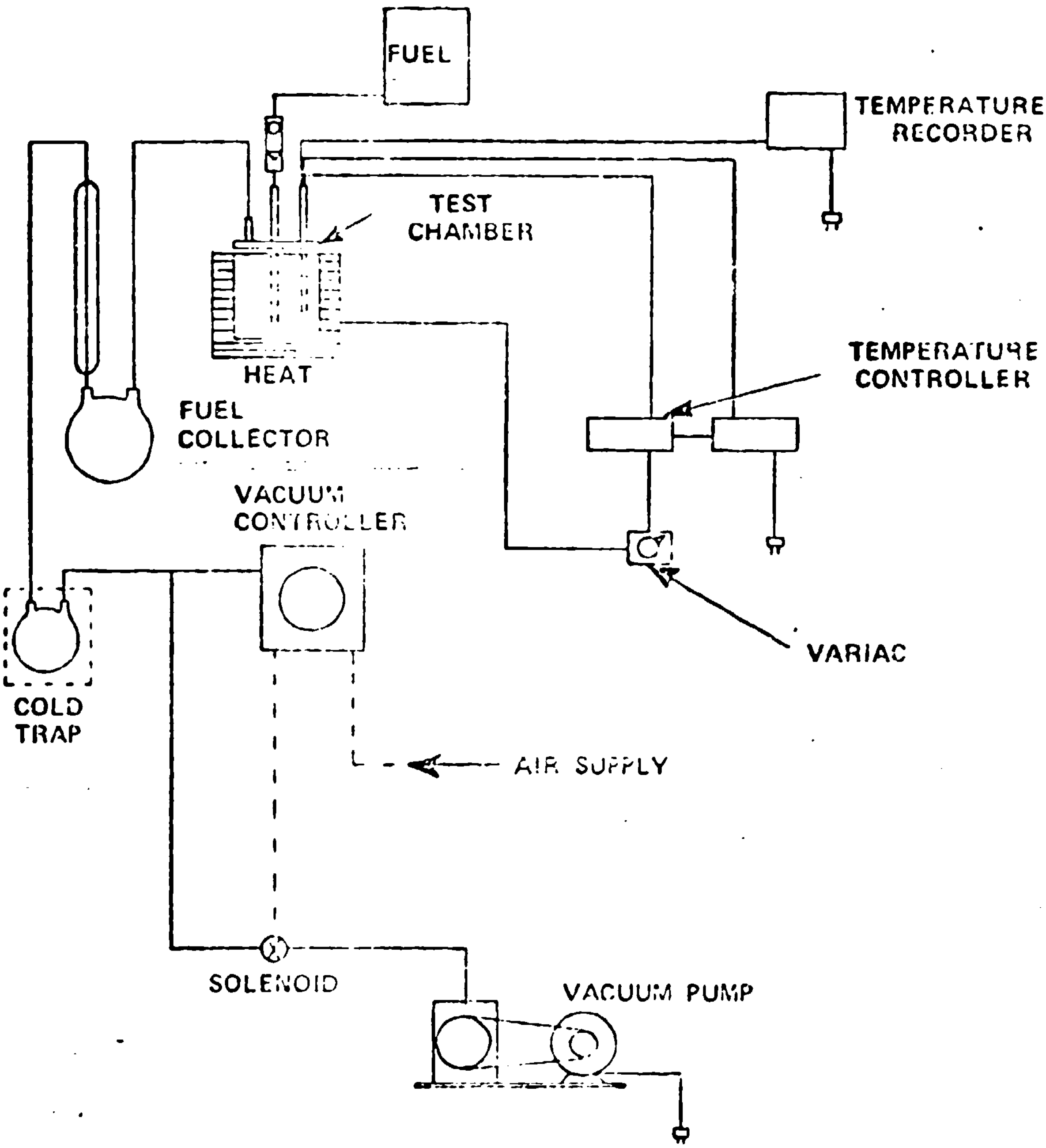


FIGURE 7 - FUEL VAPOR TEST APPARATUS

deflection model shown in Figure 8. This figure is an enlarged cross-section of a test joint in the area of contact between the test cup and plate. Assuming that (c) is an imaginary sealant filament, it can be observed that as the filament moves from point (b) to point (a), it decreases in length, until at (b) the length is essentially zero. In the test specimens being used, however, it can be assumed that a very thin film of sealant could exist at that point.

Since the joint opening and torsional deflection are set at predetermined levels during the testing, it is possible to calculate the extension of any filament (c). It is recognized that the preceding model is a gross simplification of a very complex stress analysis, but it does indicate that extremely high sealant extension can occur near the joint contact point. The high extension will be somewhat tempered by the fact that during hand injection filleting of a pre-assembled aircraft structure, the sealant may not be forced completely into the contact area. Nevertheless, it is certain that either adhesive or cohesive failure will occur if sealant is forced within .100" of the contact point, based on the high temperature physical properties obtained thus far and the joint opening and torsional deflections of .005" each.

Dynamic Test Procedure

The dynamic test specimens were prepared by first etching the titanium panels in a 7% hydrofluoric/21% nitric acid solution

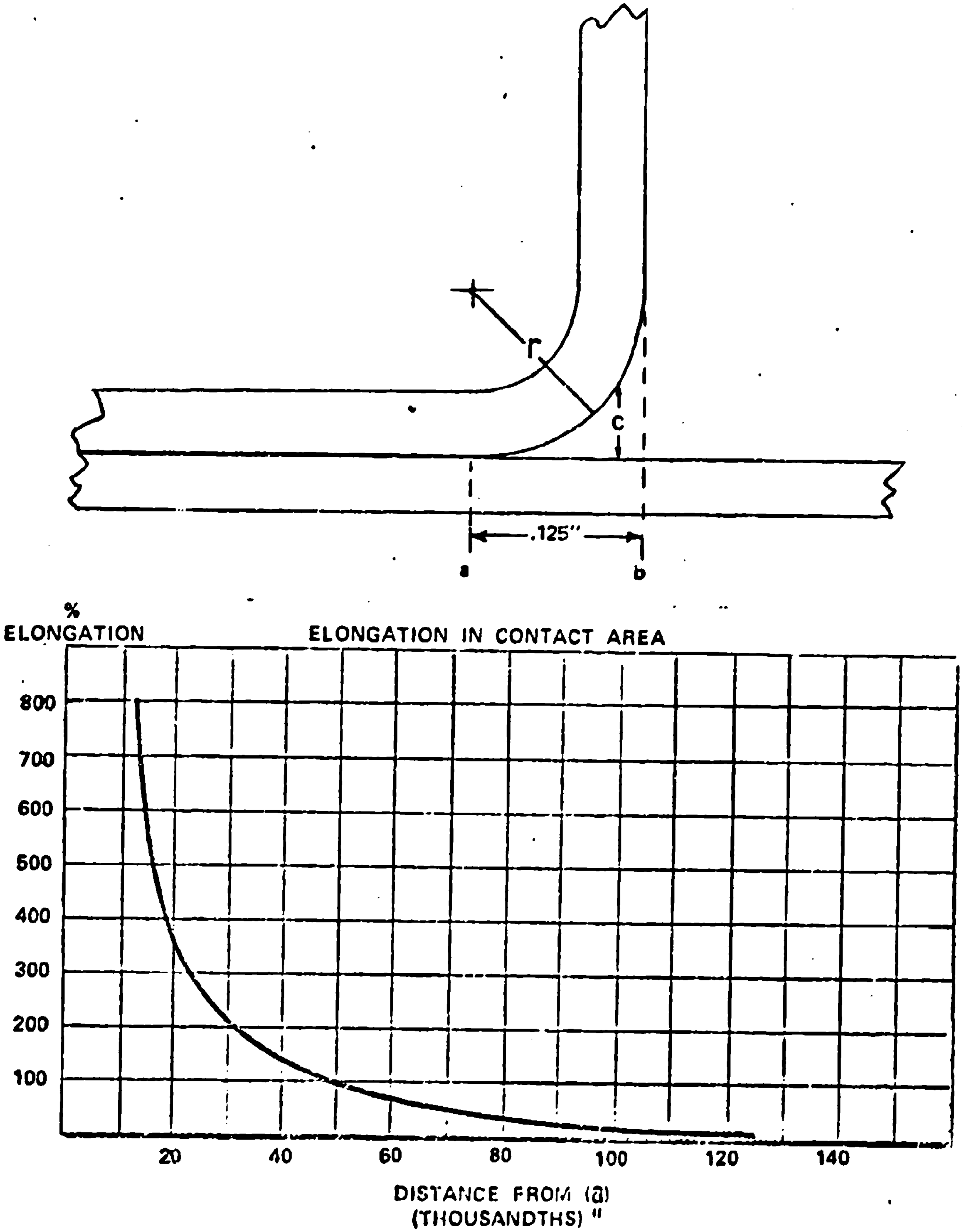


FIGURE 8 - ENLARGED JOINT CONTACT AREA

and a final cleaning in acetone before applying the appropriate adhesion primers. The cleaned, primed test cups were then placed in the molding jig illustrated in Figure 9, and sealant was injected into the jig around the outside of the cup. The titanium panels were then placed in the jig on top of the inverted cup and the top platen of the molding jig was placed on top of the plate. The entire assembly was placed in a press and vulcanized at the proper conditions for the particular material.

Finished specimens (Figure 9) were then bolted to the botton halves of the dynamic test apparatus and deflection levels were set at .005" torsional movement and .005" joint opening using the deflection meter set-up shown in Figures 10 and 11. The test chambers were then completely assembled and the test cycle was initiated. When leakage through the test joint was indicated electronically, the standard procedure was to first check the leak detector housing for the presence of fuel, and then to disassemble the affected chamber and visually examine the specimen. The specimen was then removed and rechecked for leakage by pulling a vacuum on one side of the specimen and checking for air leakage through the sealant fillet. This was accomplished by placing a bell jar, half filled with water, on one side of the panel and inspecting for air bubbles when the vacuum was drawn.

Dynamic Test Results

Poor performance of the sealants tested to date can be accounted for by a number of failure modes.

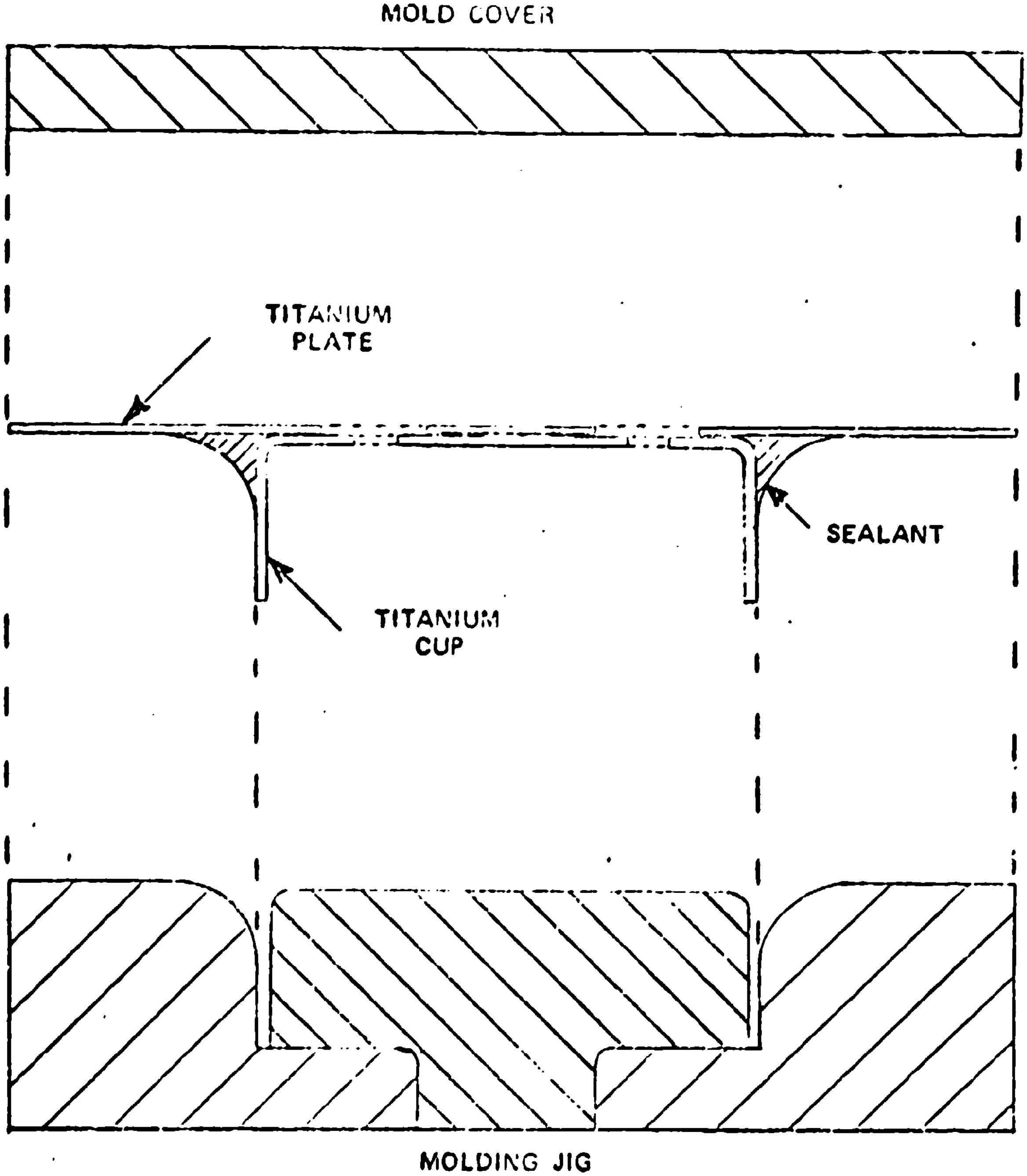


FIGURE 9 - MOLDING JIG AND TEST JOINT

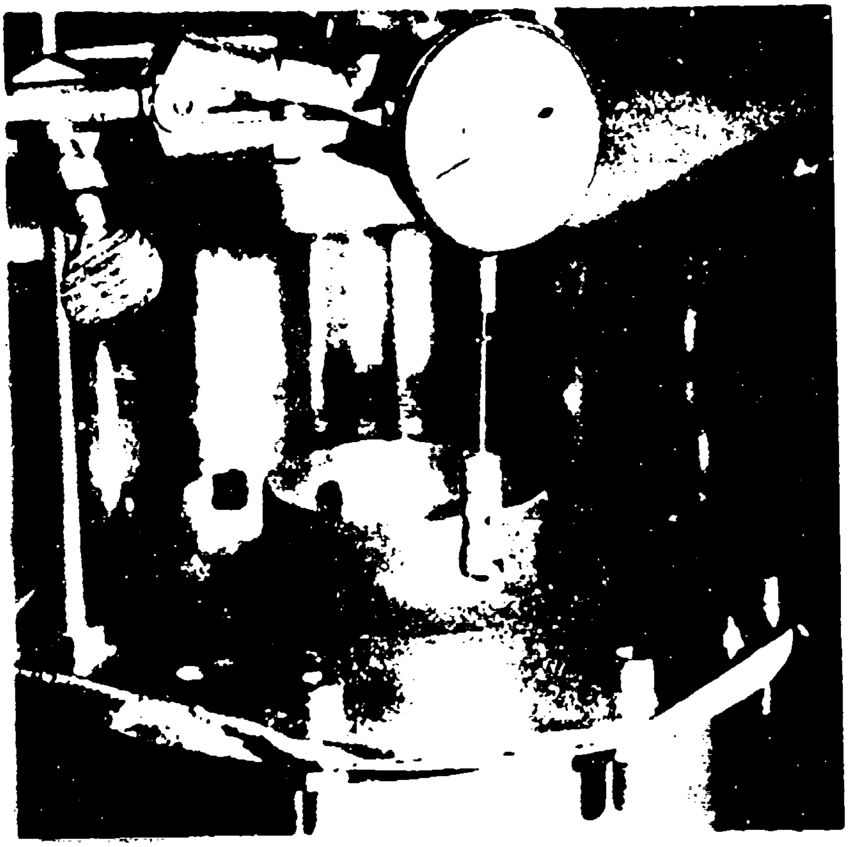


FIGURE 10 - JOINT OPENING SET-UP

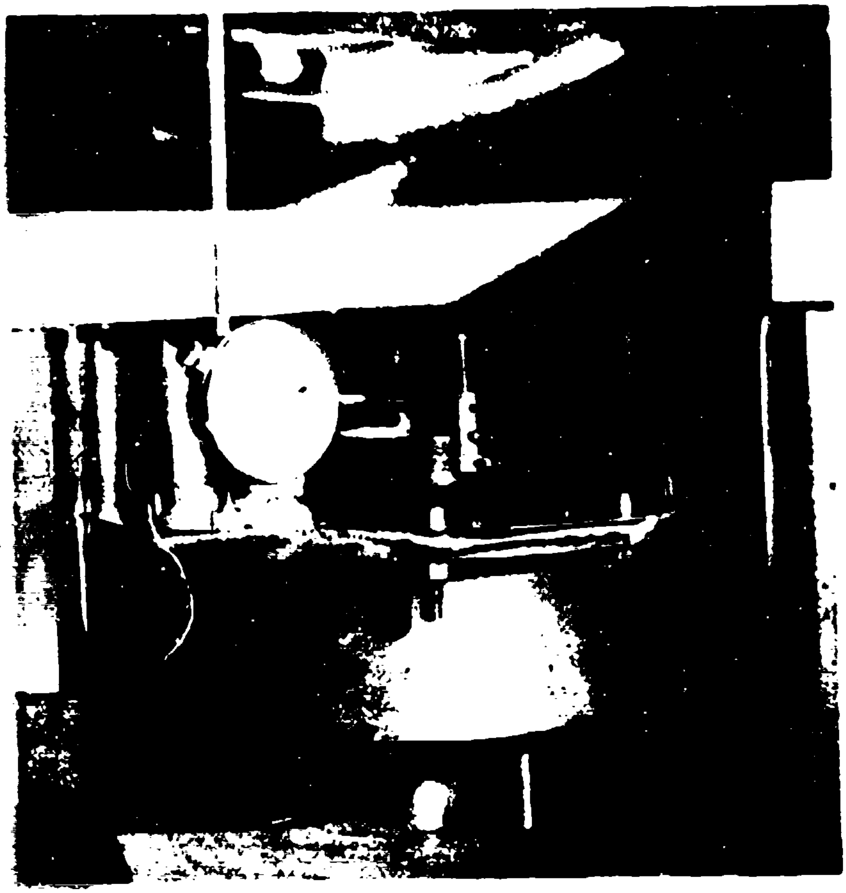


FIGURE 11 - TORSIONAL DEFLECTION SET-UP

The PRC-8802 polysulfide sealant has been partially tested both statically and dynamically.

Dynamically, the material has survived 4 hours at -65 using .005" torsional deflection and .005" joint opening. Test chamber pressure was maintained at 5 psia on the primary side and 4 psia on the secondary side. The fuel used was JP-7.

Sponging occurred in the fillet during two separate attempts to test the material with a 140°F liquid fuel soak and a 250°F vapor exposure. The first attempt was made on specimens cured for 7 days/R.T. and the second on specimens cured for 15 days/R.T.

A polyimide sealant prepared by TRW under a separate Air Force sponsored effort was tested dynamically with emphasis on low temperature performance.

Three specimens were prepared by TRW and brought to Dow Corning for testing. No physical property specimens were made available to Dow Corning but, superficial examination of the specimens showed that the sealant was a very high modulus, resinous material.

The fillets were very thin (approximately .100" to .150"), and had been applied in several applications using spray coating techniques.

The first of the specimens was installed in the test unit and found to leak almost immediately due to a small void formed during lay-up of the fillet.

The second specimen also leaked immediately, but testing was initiated checking the leak rate volumetrically at periodic intervals while lowering the temperature of the test unit step-wise to -65°F.

The leak rate over the 2½ hours required to lower the temperature to -65°F averaged about 2.5 milliliters/minute. After a 20 minute dwell time at -65°F, the leak rate increased and stabilized at approximately 20 milliliters/minute. The specimen was bubble tested under water with vacuum (approximately 28" Hg) on one side of the panel, and leakage was confirmed visually.

A third specimen was tested dynamically at -45°F for 8 hours with no leakage occurring. The specimen did fail during the first hot cycle using a ½ hour, 250°F liquid fuel soak, and a 1½ hour, 450°F vapor exposure. Failure occurred while heating to 450°F following the 250°F soak.

TRW personnel returned to Dow Corning in September, 1973, with additional polyimide samples which failed to survive long enough to collect any performance data.

Polyester samples were prepared using a 3M material. Samples were also prepared using a modified version of the same basic material. The modified sealant contained fiber reinforcement and was supplied by the Air Force Materials Laboratory. Dynamic test results are shown in Tables I & II.

Table I

Dynamic Testing of 3M Polyester

CYCLES TO FAILURE	HIGH TEMP.	LIQUID SOAK TEMP.	LOW TEMP.	JOINT OPENING	OPENING RATE	TORSIONAL DEFLECTION	TORQUE RATE	PRESSURE	ATMOSPHERE
1	550°F	250°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	4 psia	N_2 Bleed
2-1/2	550°F	250°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	4 psia	N_2 Bleed
2	500°F	250°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	4 psia	N_2 Bleed
2-1/2	500°F	250°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	4 psia	N_2 Bleed

Sealant: 3M Polyester EC-2288

Joint Type: Fillet Seal Ti-13V-11Cr-3Al Alloy

Primer: None - Brush coat of sealant cut with acetone applied and cured first.

Remarks: The high modulus and hardness of this material at room temperature probably contributed to inaccurate deflections (see text: Summary and Conclusions).

Table II

Dynamic Testing of Reinforced 3M Polyester

CYCLES TO FAILURE	HIGH TEMP.	LIQUID SOAK TEMP.	LOW TEMP.	JOINT OPENING	OPENING RATE	TORSIONAL DEFLECTION	TORQUE RATE	PRESSURE	ATMOSPHERE
1-1/2	550°F	250°F							
12	550°F	250°F							
6	525°F	250°F							
1	500°F	250°F							
4	500°F	250°F							

Sealant: 3M Polyester Fiber Reinforced

Joint Type: Fillet Seal Ti-13V-11Cr-3Al Alloy

Primer: None - Brush coat of sealant cut with acetone was applied and cured first.

Remarks: Possible inaccurate deflections (see text: Summary and Conclusions).

The first few specimens showed signs of adhesive failure, but the problem was eliminated by applying a brush coat of sealant thinned with a small quantity of acetone prior to the application of the primary fillet. The brush coat was air dried for 2 hours, then oven dried and cured for 1 hour at 300°F. The primary fillet was applied and the recommended cure cycle was followed. Although this procedure eliminated the adhesion problem, it did not significantly improve performance in the dynamic test. Splits and cracks around the fillet were the primary modes of failure after three test cycles at 250°/500°F. No difference was noted in the two types of materials.

Dow Corning® 77-085 sealant was tested using a double seal fabrication technique. The purpose of this approach was the study of tear propagation from an internal source being terminated by the interface. As shown in Table III six cycles at 250°/550° was obtained. The single seal sample used previously failed after two cycles. Physical property loss at high temperature is believed to be the cause of failure.

Table III

Dynamic Testing of Dow Corning 77-085

CYCLES TO FAILURE	HIGH TEMP.	LIQUID SOAK TEMP.	LOW TEMP.	JOINT OPENING	OPENING RATE	TORSIONAL DEFLECTION	TORQUE RATE	PRESSURE	ATMOSPHERE
1	540°F	245°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	5 psia	N_2 Bleed
2	550°F	245°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	5 psia	N_2 Bleed
2	525°F	275°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	5 psia	N_2 Bleed
*6	550°F	250°F	--	.005"	10 $\frac{cyc}{min}$	.005"	4 $\frac{cyc}{min}$	5 psia	N_2 Bleed

Sealant: Dow Corning 77-085

Joint Type: Fillet Seal Ti - 13V - 11Cr - 3AL Alloy

Primer: Dow Corning 77-123

Remarks: All specimens exhibited small splits and some adhesive failure.

*Double sealed specimen - fillet applied and cured in two layers.

SECTION V

STATUS OF EQUIPMENT AND DATA

The data presented in this report thus far was collected by the previous principal investigator, Mr. Gary Snyder. Mr. Snyder was replaced by the writer in August, 1973.

A brief orientation to the test equipment and a study of past performance quickly revealed inherent deficiencies and malfunctions that had been plaguing the test apparatus for some time. A delay in the completion of previous contract work had been primarily due to equipment deficiencies and down-time. This delay in completion of the previous contract and additional equipment problems, with resultant down-time on the present contract, have contributed to the lack of conclusive data in this report.

These problems have been due to poor equipment design and fabrication, as well as simple wear which perhaps may also be related to the design. In either case, repairs and/or modifications have resulted in loss of operating time and excessive expense. A summary of the major problems are as follows:

A. The time involved for set-up of one sample is 5½ hours.

B. Accuracy of initial adjustments for movements are lost because dismantling of the sample is required to remove the gauge and install the upper chamber half.

C. Improper torquing of sealant can occur if cam or sample are misaligned.

D. When the test cycle terminates because of a fuel leak, there are three possible causes: sealant failure around the test joint; sealant failure around the attaching bolts; or seal failure at the chamber flange; the latter two being equipment failure and undesirable.

E. Deflection and torque adjustments are erratic and inconsistant due to wear and alignment.

F. A possible safety hazard exists if a chamber seal ruptures and fuel contacts hot lamps (two fires have occurred because of this). A malfunction of a solenoid could create a fuel spill hazard when chamber is opened.

SECTION VI

EQUIPMENT DEFICIENCIES

Analysis of past and present problems plaguing the equipment led us to conclude that there were four major areas contributing to the equipment failure. A brief description of the four major areas contributing to equipment deficiencies are:

A. Chamber design and sample mounting - The chamber flange design does not provide for a leak-proof seal. A gasket material has not been found which is satisfactorily resistant to the high temperatures and jet fuel. Sample mounting is time consuming because of alignment problems and the necessity for sealing the mounting bolts (see Figure 2).

B. Torque assembly - It is nearly impossible to meter and maintain a proper adjustment. The reasons are under-design of components, wear, no provision for a direct readout, and time consuming set-up (see Figure 12).

C. Deflection mechanism - Problems include erratic adjustments, uncontrollable ¼" displacement of deflection shaft at all times, no direct readout on movements, major adjustments provided by shims under the valve base and time consuming set-up (see Figure 13).

D. Supporting devices - Valving and metering devices are inadequate. Solenoid valves are not reliable; the vacuum remains erratic and the leak detector is unreliable (see Figure 4).

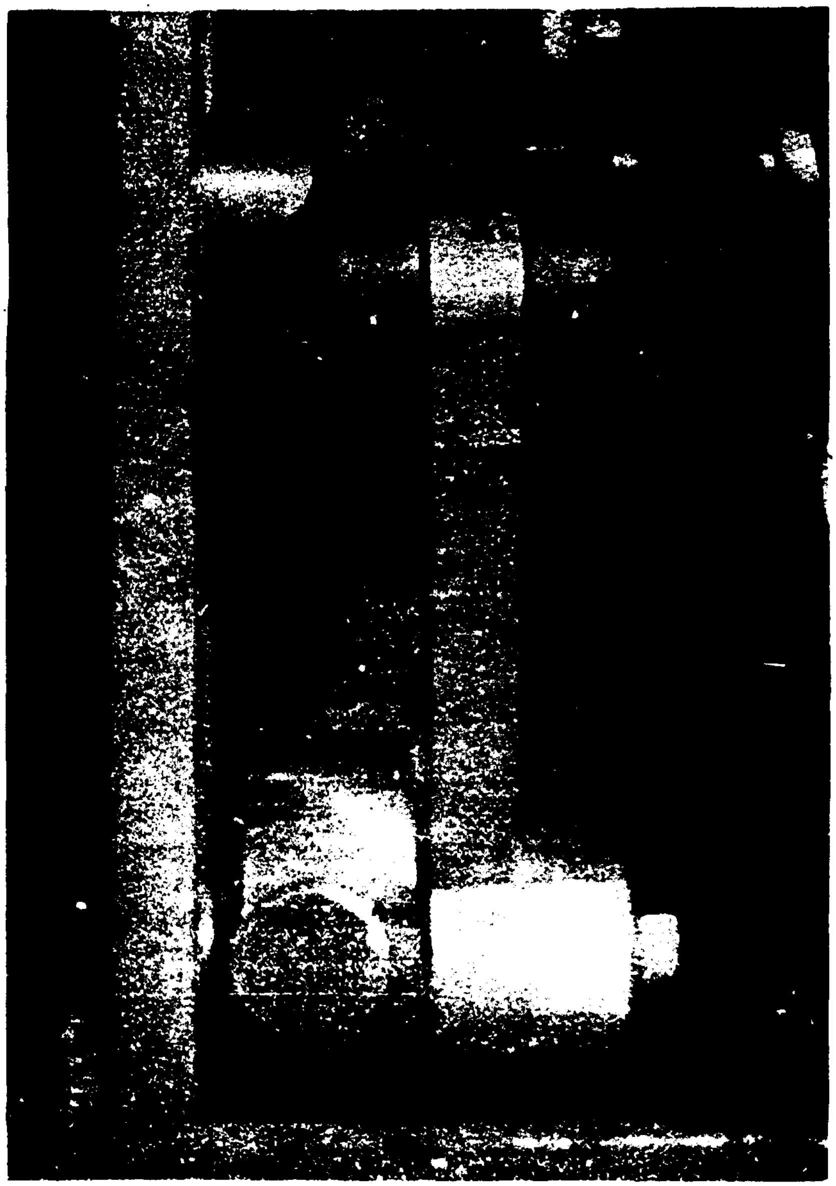


FIGURE 12 - TORQUE ASSEMBLY

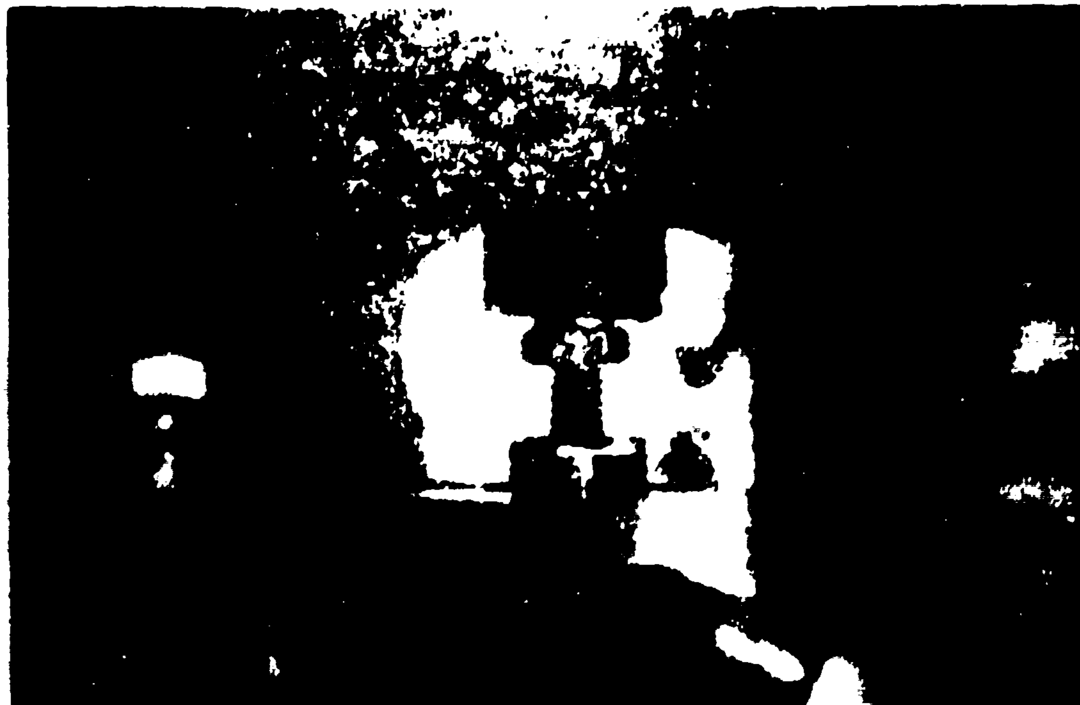


FIGURE [illegible] – [illegible] CHAMBER

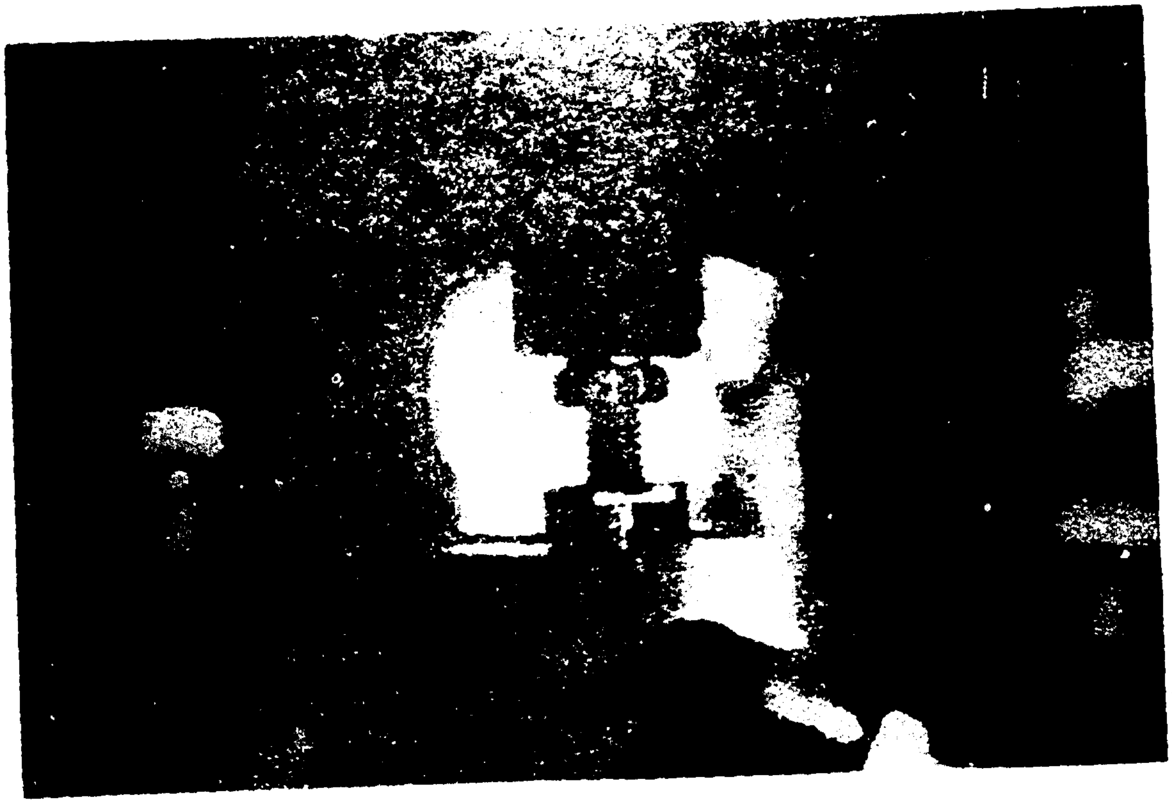


FIGURE 1 - DEFLECTION MECHANISM

SECTION VII

CORRECTIVE ACTION

A decision to halt all testing in November was initiated based on the preceding discussion. It was felt that the equipment in its present design could not be operated efficiently enough to produce reliable and reproducible data. A recommendation was made that expertise outside Dow Corning be consulted for the purpose of designing and building an improved test device. With the permission of the Air Force, an analysis of the equipment was conducted by design and fabrication companies in the area. Evaluation of their proposals resulted in the selection of three companies for further investigation. The three companies were:

1. Sebewaing Tool & Engineering Company
   Sebewaing, Michigan
   Cost Proposal: $10,000 to $12,000 to design and rebuild three units
   Estimated Time: 6 months

2. K.L.C. Enterprises, Inc.
   Saginaw, Michigan
   Cost: $74,000 to design and rebuild three units
   Time: 12 months

3. Allied Tool & Die Company

Saginaw, Michigan

Cost: $60,000 to design and build one unit

Time: 6-8 months

Following is an evaluation of the proposals and recommendations:

Sebewaing Tool & Engineering Company

Approach: (1) utilize existing concept and equipment

(2) enlarge components to reduce wear, design fine adjustments

Advantages: (1) cheap, fast

(2) precision drilling of sample lineup holes

(3) would solve problems temporarily

Disadvantages: (1) seal material not proven

(2) no direct readouts on movements

(3) subject to wear, mechanical linkage

(4) limited deflection movements because of a proposed cam roller mechanism

(5) machining and hardening of materials not included in price quote

(6) joint design restricted in shape and movements.

K.L.C. Engineering (Figures 12 and 13)

Approach: (1) perform a case study costing $500 analyzing the problems and proposing recommendations.

(2) sample attachment redesign

(3) chamber seal redesign

(4) include a third movement

(5) improve torque and deflection adjustments and accurate movements

Advantages:

(1) third movement may provide additional data of importance

(2) fast sample installation and set-up

(3) would solve problems temporarily

(4) claims to have a seal made of a reliable material.

Disadvantages:

(1) deflection motion of the cup is a distinct separation action rather than separation produced by the bending action of the plate.

(2) sample thickness is increased to reduce bending of the plate when the cup is raised from the plate.

(3) precision sample set-up. Alignment of the holes in the samples would have to be jig drilled.

(4) mechanical movements are subject to wear, need lubrication in the hot chamber area, and thermal expansion is not compensated for.

(5) adjustments are manual; calibration is needed frequently.

(6) installation at Air Force cost, not included in price.

(7) high price and long design and fabrication time.

Allied Machine Company (Figure 14)

Approach:

(1) a preliminary design proposal package

(2) demonstration of this type system being utilized by General Motors

(3) Electro hydraulic system to produce movements

(4) Chamber and sample mounting redesign

Advantages:

(1) limited mechanical linkage, reducing the wear problem

(2) constant readout of displacement or load over entire temperature range

(3) compensates for thermal expansion automatically

(4) input, varying frequency and amplitude to produce unlimited types of movements

(5) chart recording capabilities of load or displacement continually.

(6) not limited to this device or test. This equipment could be used for a number of other tests or functions.

(7) it is proven, reliable, and highly recommended concept.

Disadvantages:

(1) high price and possible time delay in fabrication

FIGURE 14 - BOTTOM CHAMBER (THERMOCOUPLE)

Proposal Recommendations

Dow Corning recommended that the testing device proposed by Allied Tool and Die be considered for design and fabrication because of the equipment's (a) flexibility; (b) accuracy; (c) data producing capabilities; (d) low maintenance; and (e) proven concept. This recommendation was based on an ethical and moral obligation of Dow Corning to produce and report valid data and to recommend the best design for the contract requirements.

SECTION VIII

SUMMARY AND CONCLUSIONS

Dow Corning has determined that the dynamic testing apparatus, in its present condition, cannot generate valid data on every type of sealant that may be evaluated in the program. In addition there are other areas, particularly in the adjustments for dynamic motion, which if redesigned could significantly improve machine downtime as well as data validity. For these reasons, all testing on contract number F33615-72-C-1594 was terminated in November, 1973. With Air Force approval, personnel expert in the design and fabrication of such test apparatus were solicited for critiquing of the present test devices and were requested to submit recommendations for a new or modified design.

The Air Force agreed to have K.L.C. Enterprises conduct a detailed diagnostic study and design proposal. This diagnostic study was purchased and provides additional information supporting the need for a redesign of the existing fuel tank sealant testing apparatus. The complete report is supplied in Appendix A. Although this report pointed out the existing problems and proposed corrective action, the purchasing of this type equipment was not recommended.

Dow Corning did agree with the preliminary design concept proposed by Allied Tool and Die and recommended that a detailed

design and fabrication package be purchased from Allied. With Air Force approval, this design and fabrication package was purchased and is supplied in Appendix B. Dow Corning recommends this design and test device be fabricated and purchased by the Air Force for further testing and evaluation of fuel tank sealants.

APPENDIX A

DIAGNOSTIC REPORT

ON

SEALANT ENVIRONMENTAL TEST MACHINE

AND

RECOMMENDATIONS

FOR

DOW CORNING CORPORATION
SEALANT EVALUATION GROUP
12CL19116-N

BY

NEAL B. VANCE
SYSTEMS ENGINEER

AND

ROBERT M. DYKES
DIRECTOR OF ENGINEERING

K.L.C. ENTERPRISES, INCORPORATED

SAGINAW, MICHIGAN

K-1536

15 JAN., 1974

TABLE OF CONTENTS

I. PREFACE

The interior of an aircraft structual space is to be sealed at appropiate joints and flanges to form a liquid-tight enclosure containing jet fuel, JP-7.

The sealant joint must retain its seal when exposed to JP-7 while being subjected to thermal and mechanical phenomina associated with the aircraft's motion.

The purpose of the dynamic test chamber is to duplicate this environment while monitoring for sealant leaks in order to establish acceptable sealant criterion.

The chamber is divided into an upper and lower portion separated by a planar surface to which is sealed a test "cup".

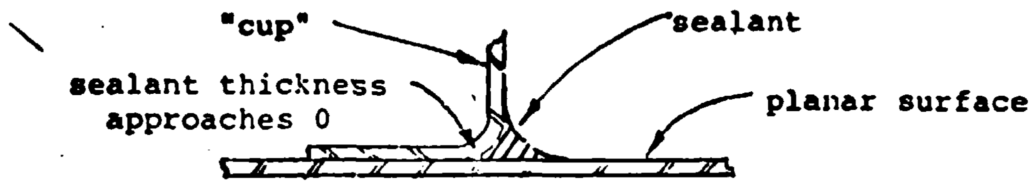
Once the chamber is closed, the chamber is purged of oxygen with nitrogen and evacuated, 2 psia upper and 1 psia lower. The chamber may then be heated (600^{o} F. max) or cooled (-60^{o}F. min) and JP-7 introduced into the upper chamber. At this time mechanical apparatus deflect the cup in various directions, amplitudes and frequencies. Deflections are designed for .030" max. in any direction.

If the sealant between the planar surface and the cup ruptures, a leak detector senses fuel in the lower chamber and shuts down the test. Conditions of the test are recorded including time of shut down.

II. TEST CRITERION

1. Joint Design.

It has been stated that the radius type "cup" joint is based upon aircraft flange joints containing radii where the radius blends into, and meets the flat surface. At this point the sealant thickness goes to zero.

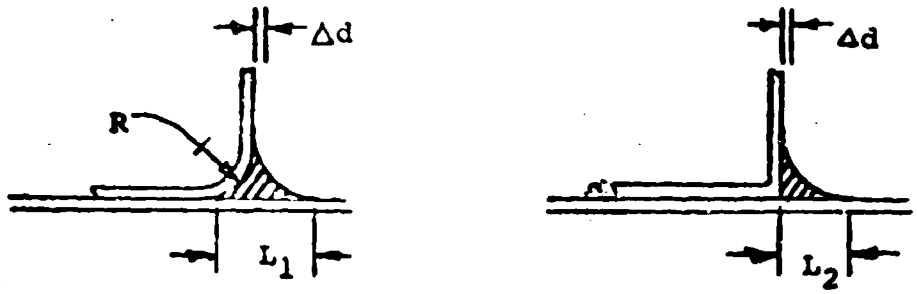


During mechanical testing the "cup" is moved in and out (relative to view above) ± .030" and raised from the surface .030". This causes sealant rupture in the very thin section, since elasticity must be near infinite with sealant thickness near zero.

Acceptable sealants are those which do not continue to rupture and separate to the outside surface over the period and conditions of the test.

However, the radius design may not represent "worst case" design. If an aircraft joint were ever constructed using a square edged flange to planar surface, it may be that the sealant's mechanical rupture would be different.

In the case of principle tensile or compressive loading of the sealant in the direction noted (to be discussed in detail under "Y" deflection), the difference is noted below.



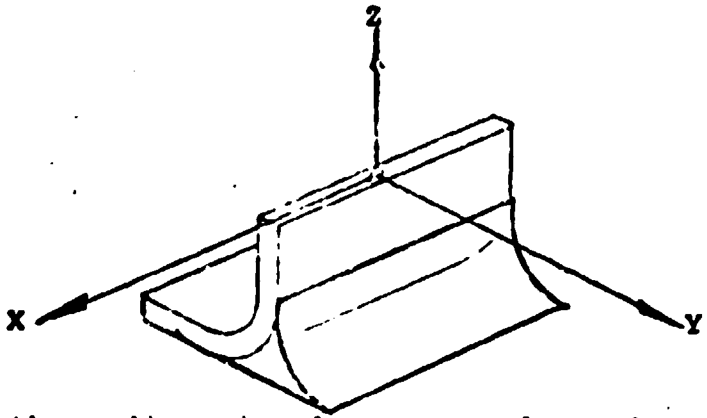
Given equal deflections (Δd) of both the radius and square edge flange design, and equal sealant fillets, the probability exists that the square edge design would fail first due to $L_2 < L_1$ for any height less than radius R, i.e. % compression would be higher

This case would also hold true for enlongation with Δd in the opposite direction. Here % enlongation would be higher in the square edge design.

The author raises this point for the use of the subscriber. It may be general practice in aircraft construction to always include radii at such joints. However if certain extruded or machined flanges or joints are used with square edges, then the point requires consideration.

2. <u>Mechanical Motions</u>

Two Directions of motion are now spelled out in sealant testing. As shown below, the flange (actually a "cup" of 3" outside diameter) is to be moved in the + X direction .030", -X direction .030", and +Z direction .030", relative to the planar surface. (Since the deflection of X is small compared to the cup radius, we shall consider linear motions).



Both these directional motions place the sealant in principle tension (enlongation of polymer chains) where as ± Y motion (which on the present test is not used) would subject the sealant to both principle tension and compression. Since tensile and compressive moduli are not generally equal for sealants, it is felt the +Y motion (or compressive loading) is essential to a conclusive sealant evaluation, especially since +Y motion is as likely to occur as ± X motion in a real structure.

III. PROBLEM AREAS.

1. "X" Deflection

X defection is designed to occur with a twisting motion of the cup with respect to the planar surface. The torque is transmitted to the cup through a hollow torque shaft. The cup is attached to the shaft by four #10 #8 socket head cap screws. At the drive end of the shaft is a crank arm attached to an adjustable eccentric driven by a variable speed DC motor through a gear reducer.

The design in principle is sufficient, however, the system suffers from "under-design". It is estimated that a high modulus sealant at -65°F, deflected a full .030" could develop torques in excess of 200 Ft. Lbs.

None of the devices now used could accomplish this load. In fact, at room temperature with normal modulus sealants, torque has been reported at 65 Ft. Lbs. for only .010" deflection. At present, most of the real deflection is lost in the eccentric device, the crank arm, the torque shaft, the cup attachment device, and slippage in the screws at the cup.

It is recommended that this mechanism be replaced. See section on "Proposal".

2. <u>"Z" Deflection</u>

Z deflection is imparted by a rod up through the center of the hollow torque shaft. A button on top of the rod deflects the planar surface up to a theoretical cup/plane/seal separation of .030". Present actuator is a "pancake" air cylinder. As the rod deflects the plane, the cup raises the cup attachment which requires a splined attachment to the torque shaft.

As the rod deflects the center of the plane, the cup raises. However, the adhesive strength of the sealant between the cup and the plane also advances a "disk" of the plane under the cup. The distance to the fixed edge of the plane from the sealant is long enough to allow this "disk" deflection to occur for almost the entire stroke of the actuator. The "fixed" edge is also subject to movement since the plane is sandwiched between gasket materials by frictional force and not accurately mechanically keyed or doweled to prevent motion.

It is recommended that this system be replaced. See section on "Proposal".

3. "Y" Deflection

No Y deflection or principle compressive loading is now specified in the test. It is recommended that this be added. See section on "Proposal".

4. Data Integrity

Because of the sealed environmental chamber, it is difficult to monitor deflection within the chamber during the test. Known instruments or transducers could not withstand the thermal and chemical variations, with acceptable economy and reliability.

At present, the deflection tests are "set-up" before the chamber is sealed. This is acceptable in principle. However, this process is very time consuming and may introduce errors since all the planar surface clamping screws must be removed after set-up so as to seal the chamber. It is possible that the planar surface could move at this time, compromising the test data.

As mentioned under "X" Deflection and "Z" Deflection, both deflection values are subject to errors caused by mechanical variations.

IV. PROPOSAL

A summary of the problems noted include:

1. Test Sample construction and test procedure contributing to lack of test conclusiveness.
2. "X" deflection mechanical device errors and lack of data

integrity.

3. "Z" deflection mechanical device errors and lack of data integrity.

4. Absence of "Y" deflection for principle compressive loading evaluation and lack of test conclusiveness.

1. TEST SAMPLE

The test sample construction appears to be a major contributor to test error and inconclusiveness.

A. Problems

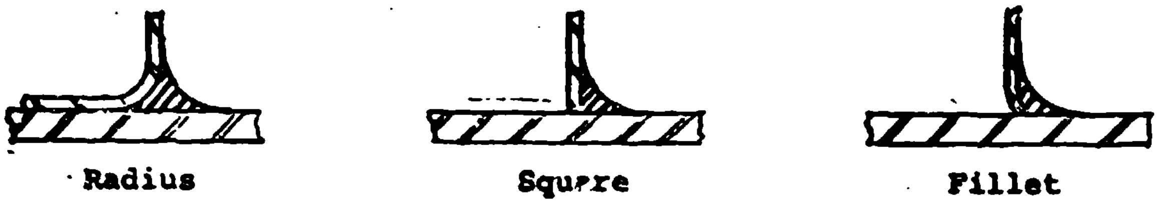
a. The cup is not rigidly attached to the torque shaft and relies on friction from the socked head cap screws to prevent angular slippage between the cup and shaft.

b. The planar surface is not rigidly attached to the chamber flanges and relies on friction to prevent angular and deflective slippage.

c. The planar surface is allowed to deflect contributing to "Z" deflection data error, because of long distance to chamber flanges and lack of planar thickness to increase rigidty.

d. The sealant lay-up does not correspond to typical aircraft construction techniques, which is done by hand. Test Lay-up is done in a press with dies forming the fillets under high pressure with accelerated polymerization and cure rates.

e. The radius joint design may not be representative of joint designs found on aircraft. Alternatives may include square edge or inverted radius (fillet) types.



B. <u>Proposed Solution</u>

a. The basic cup size of diameter, material thickness, and height should be retained. However, the cup holding attachments should be variable enough to hold different cup configurations thru rigid pins to eliminate slippage.

b. The planar surface to which the cup is sealed is to be mechanically pinned to the chamber flanges to prevent slippage for angular torque loading (X deflection) and insure rigidness during Z & Y deflection.

c. As in (B) above, holding the outer flange of the planar surface in positive mechanical rigidity will help avoid "Z" deflection data error. However, the single most important improvement in "Z", as well as "X" and "Y" data integrity would be to increase the thickness of the planar surface to eliminate deflection in this surface altogether. An examination of the test procedure and objections would perhaps point this out. In actual flight it is probably true that the joint (cup) and the adjoining surface (planar surface) may both be undergoing deflections with varying degrees of dependence to each other. The joint may be experiencing mechanical loads, say from main wing support

deflections, whereas the planar surface may be deflecting from air surface pressures. Observing the motion of the joint in direction, amplitude and frequency and likewise for the plane, implies a fixed coordinate axis space somewhere unrelated and "stationary" to some other location with respect to both these members. If in the course of observing both motions from our unrelated "stationary" point, we compiled data for both, describing their motion with time, it is mathematically and logically true that we could combine this data to describe the motion of one while considering the other stationary. That is, move our coordinate axis space to one of the two moving members and make our observations from that point of the other member.

It follows that the moving member must have independent direction, independent frequency, and independent amplitude in each of the X, Y, and Z directions in order to duplicate the relative motion.

Our proposal requires that the planar surface be increased in thickness to eliminate its deflection and motion and to independently control the motion of the cup in direction, amplitude and frequency.

The increased thickness of the planar surface will not add substantial time to the pre-heat cycle since the diameter of this planar surface will be reduced to decrease the deflective momemnt arm from the chamber

flange to the test cup, and thus require an almost equal amount of heat to bring the planar surface up to temperature.

d. We strongly recommend that sealant lay-up be done by hand or other methods which closely duplicate the method required during actual aircraft construction. The data generated by this may be an added benefit in establishing methods and criterion for the aircraft companies in acceptable sealant lay-up.

e. As previously noted, proposed fixture design should include the flexibility to test variations of the three possible joint designs; radius, square, or fillet. Also the proposed design incorporates the flexibility to add joint designs of many various configurations including grooved mastic seals and other variations.

2. X DEFLECTION

X deflection error is result of undersized torque shaft and absence of an accurate adjustment device.

Our proposed design would provide a torque shaft with enough torsional strength to minimize torsional deflection error and accurate adjustment/read-out device to insure the test is truely represented by the read-out.

Also by improving the test sample construction as noted previously, unwanted deflections or slipping motions contributing to X deflection data errors would be eliminated.

X deflection amplitude in + or - direction and X defle

frequency would be independently adjustable within the parameters of the test.

3. Z DEFLECTION

Z deflection errors principally occur due to test sample construction. By increasing the rigidity of the planar surface and its mounting configuration, our porposal would insure that if the Z deflection shaft raises some Z_o distance, the cup would raise off the planar surface and subject the sealant to the same Z_o enlongation. Z deflection amplitude and frequency would be independently adjustable within the parameters of the test.

4. Y DEFLECTION

Y deflection was not included in the present test machine design. As noted earlier we feel that the test is not conclusive unless the sealant polymer is subjected to both tensile and compressive type loading.

Our proposal would allow the sealant to be compressively loaded in any independent angular position from 0 to 359^0 at independently adjustable amplitudes and frequencies.

V. COST ESTIMATES

1. Engineering

Good engineering design for this machine centers around top quality test fixture design with tolerances into the tenths of a thousandth of an inch as required. Any less rigorous approach will only result in down-time, frustra-

tion and inconclusive results.

Our proposal eliminates the errors inheritant in the old design by carefully considering the purpose and parameters of the test and the associated driving members, through all possible error-causing linkages to the prime mover.

Total system engineering will include:

1. Frame design to fit within the confines of each machine space if possible.
2. Total engineering of mechanical systems to tolerances and accuracy required, including X, Z, and Y deflection systems.
3. Interfacing present fuel, heat, cooling, purge and vacuum systems utilizing "explosion proof" techniques.
4. Additional control systems for DC drives, "explosion proof" construction design.

2. Build

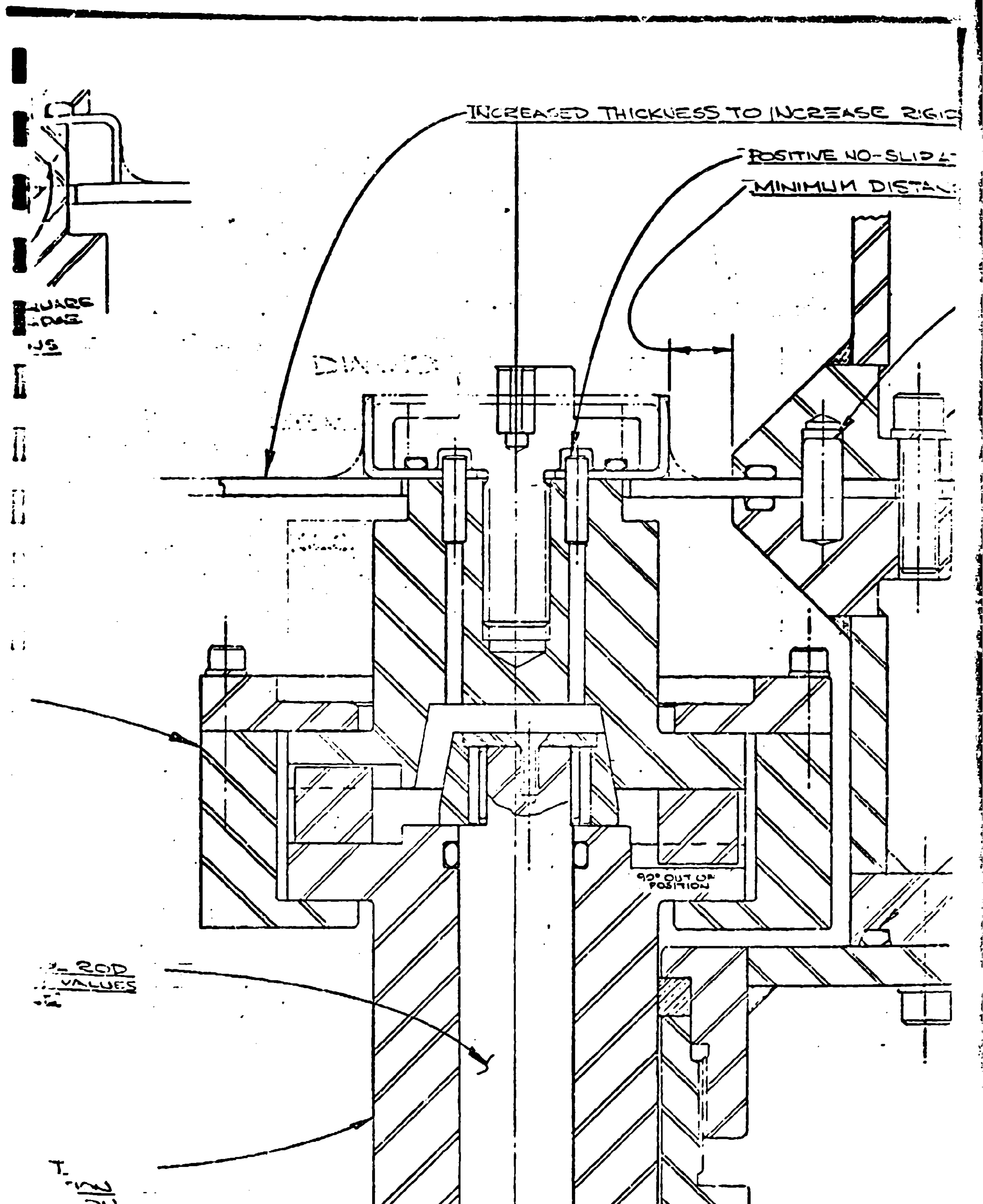
Due to the corrosive nature of high-temperature JP-7, much of the chamber and mechanical system will require stainless steel construction.

Portions of the deflection system components will require precision grinding and assembly.

Purchased items will include two additional variable speed drive systems (one drive system is on hand in present equipment).

The main frame will require jig boring for correct fixture alignment.

Both engineering and build estimates assume that portions of the existing system will be used on the new system. If in the opinion of the engineer it is discovered that these systems do not meet the ccuracy and reliability requirements of the new design, then additional costs may be incurred.



INCREASED THICKNESS TO INCREASE RIGID
POSITIVE NO-SLIP
MINIMUM DISTA
90° OUT OF POSITION
ROD
VALUES
NOT TO SCALE

PROPOSED
SYSTEM
SCHEMATIC
-for
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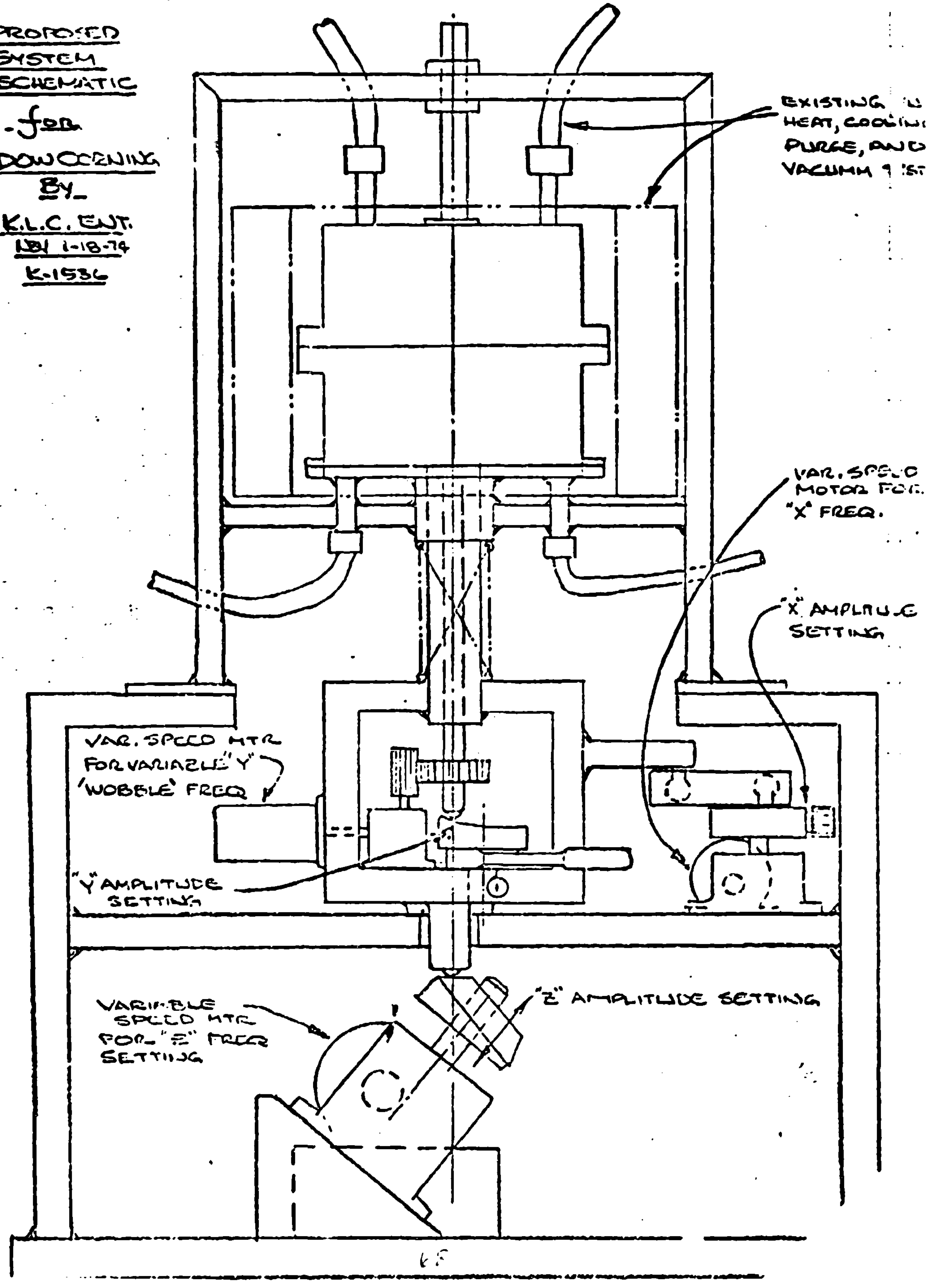

ALLIED TOOL AND DIE COMPANY

JAMES RD.
SAGINAW
MICHIGAN
48605

TELEPHONES
PL. 5-5384
PL. 5-5385

EXPERIMENTAL SPECIALISTS IN PRECISION AIRCRAFT AND AUTOMOTIVE MACHINING

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APPENDIX B

April 15, 1974

Dow Corning Corporation
Midland, Michigan 48640

Attention: Mr. John Baker

Reference: Air Force Contract No. F33615-72-C-1594

Gentlemen:

We are pleased to submit the following Design Proposal for the test unit for testing of your sealants for airplane wing gas tanks as per your specifications.

TOOLS • DIES • FIXTURES • GAGES • CUSTOM MACHINES

PROSPECTUS--

AN ELECTROHYDRAULIC, SERVO-CONTROLLED FATIGUE TEST SYSTEM OF CLOSED LOOP DESIGN

PROSPECTUS— An electrohydraulic, servo-controlled fatigue test system of closed loop design, for mechanical testing of sealants for aircraft components of titanium, and/or other components subject to a variety of tension, compression, and torsional fatigue, in a simulated environment.

General Information

The test system described in this prospectus will evaluate sealant adhesion and fatigue resistance. The system is comprised of established testing concepts commonly employed in industry, universities, and government facilities. It is the preferred test medium where accuracy and reliability are prime considerations. Calibration of both load and displacement functions is traceable to the National Bureau of Standards. Both of these parameters may be monitored continuously during the testing procedure.

The basic purpose of this particular test system is to measure the fatigue resistance of sealants used to bond together aircraft components formed from titanium alloy sheet stock. Specimens can be tested under controlled atmospheric and environmental conditions which simulate actual conditions expected in the functional life of the sealant, and can include total immersion in aircraft turbine engine fuel.

The closed loop design and control for this test system means the system is continuously monitoring itself. Load and displacement levels determined at the beginning of each test will self adjust to variables not related to component failure. The system immediately terminates all test functions when the test is completed. Completion may be defined for the system in the following terms:

. . . Exceeding preset limits for load and/or displacement

. . . Leakage from the atmospheric chamber

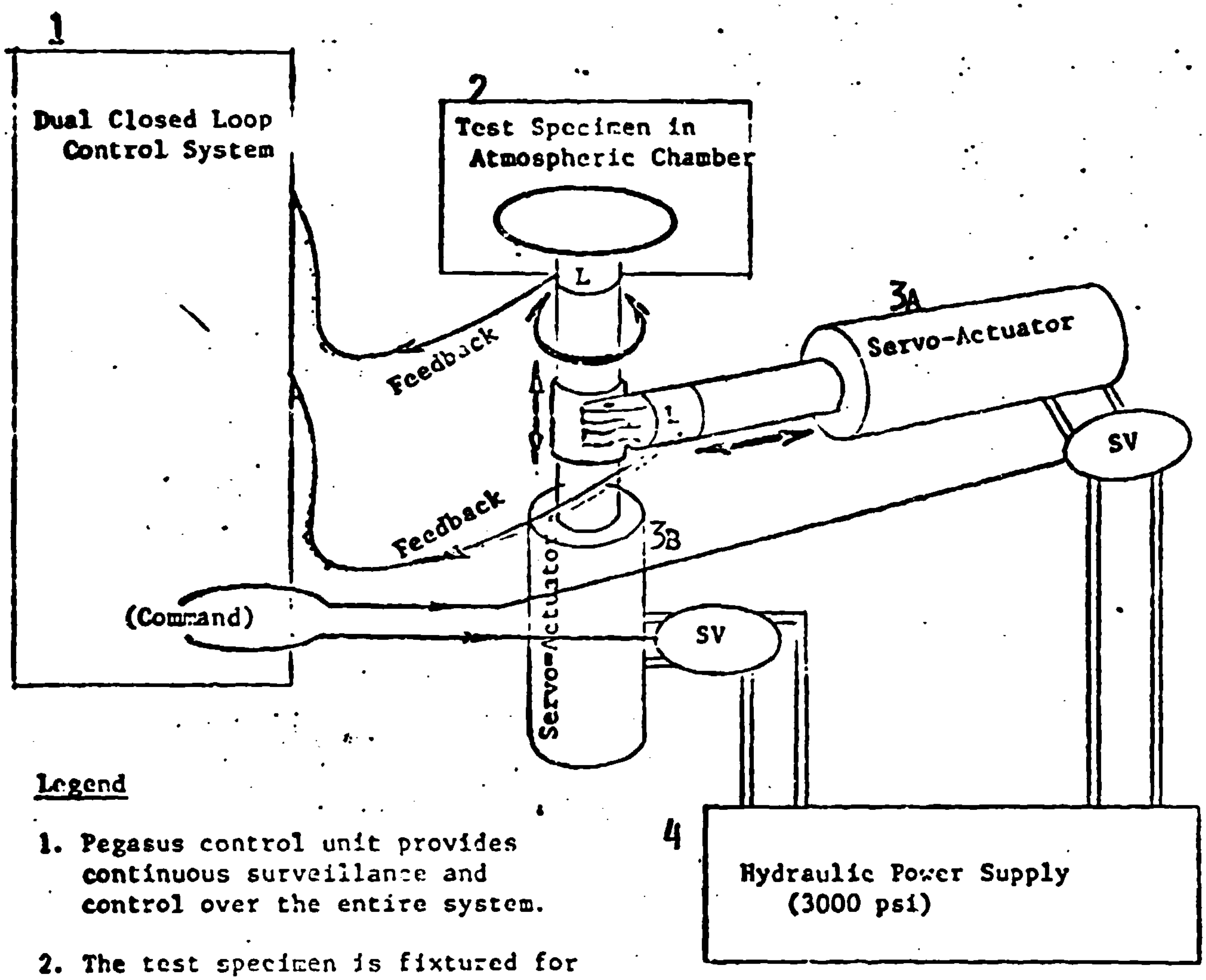
. . . Reaching a predetermined number of test cycles.

The closed loop concept enables unattended 24-hour/day testing.

This test system also works effectively for testing any other small part which might be subjected to repetitive mechanical loading of a controlled nature.

ELECTROHYDRAULIC SERVO-CONTROLLED FATIGUE TEST SYSTEM

BASIC FUNCTIONS—



Legend

1. Pegasus control unit provides continuous surveillance and control over the entire system.

2. The test specimen is fixtured for rapid set-up in a chamber capable of simulating the various environments in which sealants are to be proven.

3(a & b). Servo-Actuators (Hydraulic rams), that provide the linear force required for testing.

4. Standard hydraulic power supply, system psi adjustable, 500-3000.

L= Load Cell SV= Servovalve

The Closed Loop for Mechanical Test Control

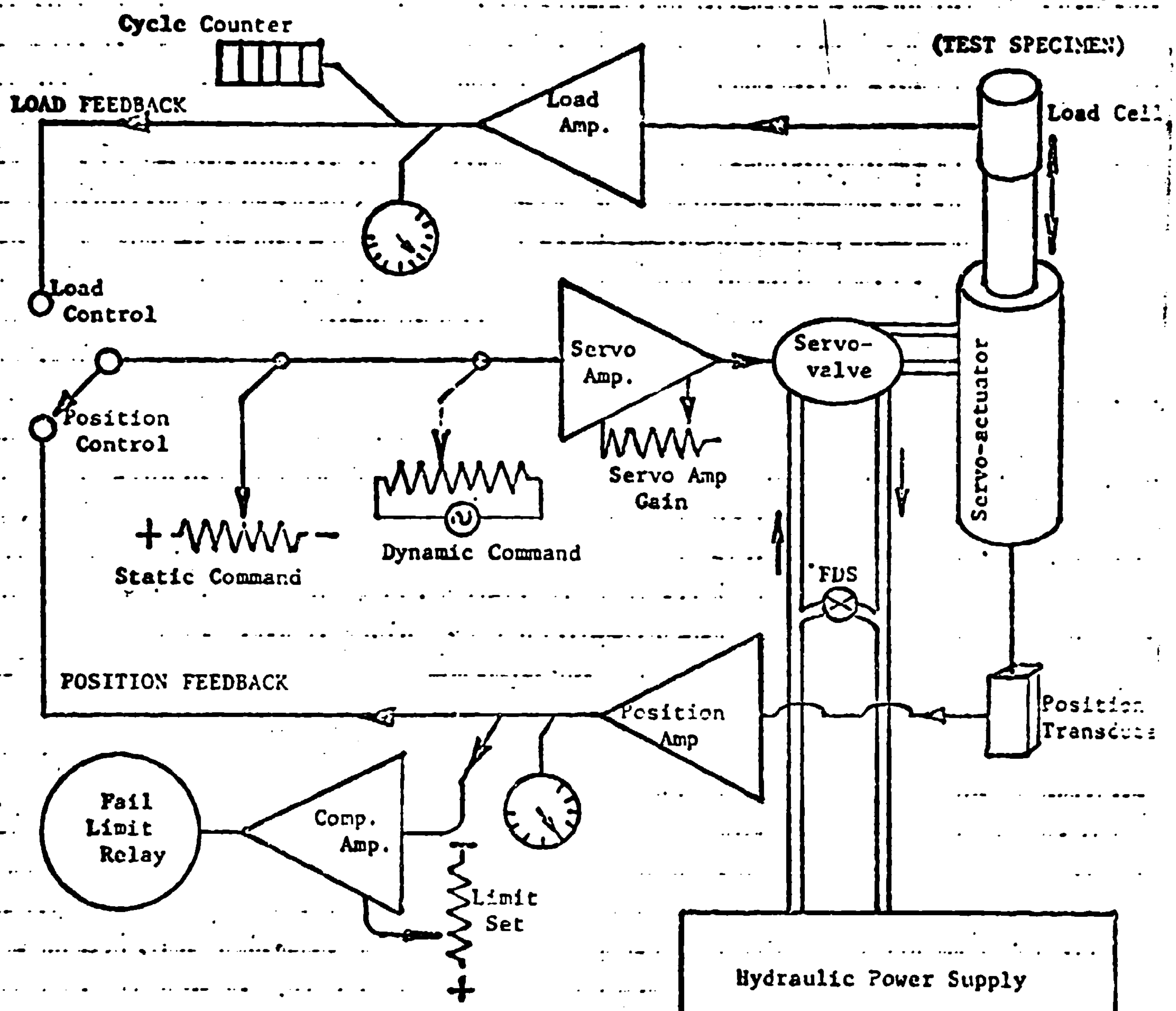
A closed loop control differs from conventional test control systems in that the closed loop is self-controlled within the parameters you establish. The system itself knows the physical position and functional effort of each of its components at any given moment. The system uses this information to compensate for variables during the test. For example, changes in testing temperature may vary the test materials' resistance to deflection. This may alter the effort required to maintain your preset load and displacement parameters. The closed loop controls continuously monitor these criteria, and adjust the system functions to maintain constant load and displacement levels throughout the life of the test specimen.

When preset limits for load and displacement are exceeded as when the specimen fails, or when a leak occurs in the atmospheric chamber, the system "dumps." That is, all power is removed and hydraulic pressure is released within ten milliseconds. This instantaneous termination prevents "hammering" of the interfaces at the defect, and makes detailed inspection possible at the physical point of failure.

Closed loop control happens to be economical because of reduced manual surveillance. Efficiency is superior because of its potential for uninterrupted operation. (One technician can conduct tests on several servo-controlled systems at the same time.) The critical value of the closed loop control, however, is that no amount of human surveillance can supply the control, accuracy, and verification that are absolutely essential in the design of aircraft components.

CLOSED LOOP CONTROL SYSTEM (POSITION CONTROL & LOAD CONTROL)

(Note: Circuitry shown is for a single-actuator system.)



*FDS= Failure Dump Solenoid

Notes: -System can be controlled with a static command and/or a dynamic command.

-Provides direct readout for load and for position.

-Diagram shows system set for position failure detection to energize FDS, removing all hydraulic pressure, deactivating motor and pump.

Fixturing

Custom fixtures for the test system are designed in conjunction with standard hydraulic ram mounting configurations to provide the tension-compression and rotational action specified for the sealant test. Fixture details related to the test specimen itself are designed for quick and easy specimen change.

Included in the fixturing are provisions for the required atmospheric and environmental variables -- minus 65° to plus 600° F, pressurization with air or nitrogen, and capability to totally immerse the specimen in aircraft turbine engine fuel. Existing Dow equipment will be used wherever possible without compromising test criteria.

All linkage and transmission hardware are designed for simplicity of operation, and therefore good reliability. We find this an important consideration in achieving consistant test results. There are no cams, screw actuators, or rack and pinion linkages in the test system.

Advantages of In-House Testing

Electrohydraulic servo-controlled fatigue test systems are well-established, and are widely used in industry and government. The technology is well developed, which makes this test medium readily accessible to Dow testing laboratories.

There are natural advantages with in-house testing in control, information turnaround time, and consistency of test methods. In-house testing is the most dependable means of assuring the security of test data. Tests performed in your own facilities by your own technical personnel generate familiarity with the product itself--a factor that is generally considered valuable in the development of new products for critical applications.

Component Specifications*

The electrohydraulic servo-controlled fatigue test system described in this prospectus will provide a minimum of .030 P-P linear motion at 100 cycles/minute, and through fixturing, 2-3° rotary motion at the same rate.

Electronics— in free-standing console with Sola isolation transformer, cooling fan, writing top drawer, casters.

- — Two Exact 120 Function Generators
- — Two Pegasus 551B load and displacement servo-controllers with automatic zero correction
- — One Tektronix 510 3N-D13 Storage Oscilloscope with dual trace amplifier and dual time base.
- — One AC power on-off and pump on-off control panel
- — Necessary communications cables for electronics

Hydraulics--

- — Two servo-actuators (hydraulic rams), each with Koehring servo-valves, load cells with 500-lb rating, integral LVDT with 6-inch total stroke, and required hoses
- — Two mini-hydraulic accessory modules with hoses
- — One PS-10F-20-18 Standard Hydraulic Power Supply

Fixturing-- to be determined after review of existing Dow fixtures in order to prevent unneccessary duplication.

Services--

- -- Completion of one system for checkout at Allied Tool prior to installation in your facilities
- -- Training of Dow personnel in use of the system
- -- Maintenance and troubleshooting manuals